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Foreword

The Commonwealth Scientific and Industrial Research Organization has decided to publish this new periodical, the Australian Journal of Marine and Freshwater Research, to provide a medium for the publication of the results of original investigations on sea, estuarine, and freshwater fisheries and cognate subjects.

It is not intended to issue the Journal at set periods, but as the accumulation of suitable material dictates.

A BIOLOGICAL STUDY OF THE ANCHOVY, *ENGRAULIS AUSTRALIS* (WHITE), IN AUSTRALIAN WATERS

By M. BLACKBURN*

[*Manuscript received December* 15, 1948]

Summary

A biological study was made of the common Australian anchovy, *Engraulis australis* (White), which occurs in coastal waters south of the Tropic of Capricorn. The occurrences in Victorian waters, where the only fishery exists, were those most fully investigated.

There are three subspecies which are easily recognized by their mean vertebra numbers, in combination with the region of occurrence. *E. a. australis* (White) occurs in Queensland and in all but the southernmost waters of New South Wales. *E. a. antipodum* Gunther ranges from the border region of New South Wales through Victorian, Tasmanian, and South Australian waters. *E. a. fraseri* n. subsp. occurs in Western Australia. Each subspecies is further divided into local populations which intergrade.

The subspecies *antipodum* grows to about 2.3, 2.9, 3.5, 4.2, and 4.7 inches of total length (mean sizes) at ½, 1½, 2½, 3½, and 4½ years respectively. The greatest known length is 6.2 inches. Sexual maturity is usually attained at 1 year. Spawning occurs mainly in the inlets, in summer. The fish inhabit principally the inlet waters, but as they become older they tend to move out to sea in winter and return in spring. Within the inlets, the younger fish are usually found furthest from the sea. There is a special brackish-water population in the rivers entering the Gippsland Lakes.

The growth rate of the subspecies *australis* is similar to that of *antipodum*, but the life history appears to differ in many ways, although the full facts are not clear. There is more spawning in the colder months, and it takes place mainly at sea.

The subspecies *fraseri* occurs both in inlets and at sea, but the data are insufficient to establish the life history. The growth rate is approximately the same as elsewhere.

Anchovies occur in large numbers in certain inlets, where they can be caught easily with haul seines. In Port Phillip Bay there are proficient anchovy fishermen who cannot dispose of much of the fish they are able to catch. The fish would be suitable for canning whole, for fish paste (for which a little is used now) and for live-bait for tuna fishing. They would not be suitable for oil reduction.

The scale-reading (age) studies yielded some results of general academic interest. The fish-length/scale-length relationship is not the same in all regions, and this affects calculations of growth rate. There is slight variation in growth rate between localities, and possibly between year-classes and sexes; and apparent but not real variation between age-groups, and between different sizes in each age-group.

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I. INTRODUCTION

This paper is a further contribution to the series of biological studies on Australian clupeoid fish. The work has been concentrated upon two species, the pilchard (*Sardinops neopilchardus*) and the anchovy now studied. This was because of their abundance, widespread and similar distribution, possible availability for certain forms of mass-catching, and many potential uses. Also, both have close relatives, some of which have been studied, in other parts of the world. There were thus many points of interest that might arise from comparisons between morphological characters, growth rate, life history, etc., in material of both the Australian species and other species, for each of the genera concerned.

Most of this study deals with anchovy occurrences in Victorian waters, especially Port Phillip Bay. Because of the fishery in that area there was more material available for study, and there were specific problems requiring special attention. The work has helped to interpret some of the scantier data from other places, although in some cases the general conditions are obviously not the same as in Victoria.

II. RELATIONSHIPS AND GENERAL DISTRIBUTION

McCulloch (1920, p. 43) listed the references to the species, and these were brought up to date by Blackburn (1941, p. 72). Four published references have appeared since, namely: Dakin and Colefax (1940, p. 203, Plate iv, Fig. 3), who repeated previous observations on the eggs; Phillipps (1940, pp. 5-7), who dealt with occurrences in New Zealand; Fowler (1941, pp. 693-694), who gave references and taxonomic particulars; and Mack (1941, pp. 107-112), who mentioned occurrences in the Gippsland Lakes. These writers referred to the species under the name used here, *Engraulis australis* (Plate 1, Fig. 1).

Jordan and Seale (1926, p. 388) referred the following species to the genus *Engraulis*: *E. encrasicholus* (L.), from Europe and northern Africa; *E. mordax* Girard, British Columbia to Mexico; *E. ringens* Jenyns, Peru and Chile; *E. japonicus* (Houttuyn), Japan and China; and *E. antipodum*, synonymous with *E. australis* (White), southern Australia and New Zealand. Two other species since included are *E. anchoita* Hubbs and Marini, from Argentina, and *E. clarki* Hildebrand, from Pacific Central America (Hildebrand 1943, pp. 18-20). *E. capensis* Gilchrist, from South Africa, also seems to belong to this genus (Gilchrist 1913, pp. 62-64). Jordan and Seale emphasized that the genus was the only cosmopolitan one in the family Engraulidae, "and the only one confined to temperate seas" (p. 356). The latter observation no longer stands, but, broadly speaking, the genus is distributed mainly in the subtropical and temperate waters, whereas all the other genera have their centres of distribution in the tropics.

Hardenberg (1933, esp. pp. 240-242) claimed that the differences recognized by Jordan and Seale between *Engraulis* and another genus, *Anchoviella,* are very difficult to maintain; and he further asserted that there is no valid distinction between these two and another genus, *Stolephorus,* which Whitley (1940, p. 403) re-named *Amentum.* He therefore proposed to combine all these under the oldest name "*Stolephorus.*" In the present author's opinion, Hardenberg did more or less dispose of the distinctions between *Engraulis* and *Anchoviella* as suggested by Jordan and Seale, but failed to show that either should be linked with "*Stolephorus.*" Hildebrand (loc. cit.) was not concerned with "*Stolephorus,*" but did admit (p. 11) that it is very difficult and possibly incorrect to separate *Anchoviella* (and some other tropical American genera) from *Engraulis.* However, "with considerable modification in definition" he was able to retain most of these genera and indicate a new basis for distinguishing *Engraulis,* with the species mentioned above, from the other members of the family.

There are some other engraulids in Australian waters besides this species, but they are almost entirely confined to the Tropics. Three of them — *Thrissina aestuaria* (Ogilby), *Scutengraulis hamiltoni* (Gray), and *Amentum carpentariae* (De Vis) — are also on record from southern Queensland. They are not true "anchovies" in the strict sense that *Engraulis australis* is, the latter being very closely related to the fish of that name in Europe (where the term originated) and Pacific North America. In these two regions, and in Japan and possibly elsewhere, the species of *Engraulis* support some moderate-sized fisheries, the product being variously used for salting, canning, paste making, oil and meal reduction,and bait (including tuna live-bait).

Furthermore, this species is the most widespread and potentially important member of the family in Australia, occurring in all waters south of the Tropic. Thus it is permissible to speak of it as "the anchovy" of Australian waters as is done in the title of this paper. However, in Victoria, the only State in which it has attracted any real attention from the trade, the fish is mostly spoken of as "whitebait," "smig," or "bluebait." As the latter two names may also be used for other clupeoids in the same waters, and as the former is more associated in the public mind with quite different kinds of fish from New Zealand and Tasmania, these vernacular names are not to be recommended. It is definitely in the trade interest to encourage the use of the more specific, legitimate, and generally attractive name, "anchovy."

The anchovy occurs in all Australian waters south of the Tropic of Capricorn, but further north it is virtually absent, so far as is known at present. On the east coast the northernmost definite record is from the Capricorn Islands (Blackburn 1941, p. 73); the *Engraulis heterolobus* of Klunzinger (1879, p. 415), from near Townsville in about Lat. 19° S., is doubtfully placed in the synonymy by some authors. For Western Australia the most northerly definite record is from Red Bluff, just below the Tropic (Blackburn 1941, p. 122). Specimens taken at North-West Cape, in about Lat. 22° S., were thought to be this species when examined in the field, but were subsequently lost. Between these limits the anchovy has been found in many places in the southern waters of Australia, including southern Tasmania (loc. cit., pp. 74, 82-83).

This range is almost identical with that of the pilchard (*Sardinops neopilchardus*) in Australia. That form has been recorded from Sandy Cape in Queensland, not far below the Tropic (loc. cit., p. 34), from Red Bluff and thence southwards in Western Australia (unpublished records) and from numerous intermediate places in southern Australian waters, including southern Tasmania (loc. cit., p. 119). The only important difference is that the pilchard is relatively scarce in Tasmania, at least in the south, whereas the anchovy is not. Both species also occur in New Zealand, although the reported range of the anchovy is more restricted (loc. cit., pp. 21-22, 74).

III. The Anchovy in Victoria

(a) Distribution, the Fishery, and Variations in Supply

The only Victorian locality where there is any sustained anchovy fishing is Port Phillip Bay. Indeed, this is probably the only Australian locality where any fishermen are engaged full-time in catching any clupeoid fish. These operations have been going on for at least 40 years.

Up to 1946, the principal demand for the fish was as bait for amateur anglers. Other species caught for the purpose were the pilchard and another clupeoid, the blue sprat (*Stolephorus robustus*), and atherines, but the anchovy was generally the most important by weight of catch. Catch records are not available, but the annual anchovy production was probably always well below 50 tons. However, as the average pre-war price was about one shilling per pound (rising during the war), this fishery was able to provide a modest livelihood for several men. The principal means of capture for the bait market was (and is still) the hoop-net. This is a bag of fine-meshed netting with the mouth lashed to a circular metal frame, which is lowered from a pier a few feet into the water, burleyed with pollard or boiled potato, and hauled up quickly when it contains a few pounds of fish. The hoops are about 9 ft. in diameter, the total depth of the net is about 12 ft., and the mesh-size is $\frac{1}{2}$ in. at the bottom, increasing to $\frac{3}{4}$ in. above. A catch of about 20 lb. for a few minutes' submergence is considered good, though individual hauls go to about 75 lb. and the average is about 5 to 10 lb.

The centre of this fishery is at Port Melbourne, in Hobson's Bay, where there were about 10 men so engaged (mainly full-time) in 1942, although there were said to have been about 30 before the war. These men catch pilchards by the same means when available, the principal season of occurrence being usually the same for both species, from about October to May. Small quantities of blue sprats are taken incidentally, but the main fishery for these is in the Sorrento and Corio Bay (Geelong) areas, where beach-seines are used. The fish are sold boxed in the Melbourne market, with salt added by the fishermen. To discover the average annual per capita yield by this method, records of the deliveries of four men to their market agent were obtained from the latter's day-books, for a period covering five consecutive fishing seasons (1937-38 to 1941-42). The average catch per man per season (averaging about eight months) was of the order of 3,000 lb. of anchovies and 2,000 lb. of pilchards (see Section III (*e*)).

Geelong is the only other locality where there is any sustained fishing for bait. Pilchards are not common here and the anchovy is the only species significantly fished, again mostly in the warmer months. Beach-seines with small-meshed bags, in addition to hoop-nets, are used. As is shown later, the anchovies caught here are mainly larger than those at Port Melbourne and are called "bluebait," a term applied elsewhere to the blue sprat. The anchovies taken at Port Melbourne and elsewhere in the Bay are called "whitebait."

The year 1946 saw some important changes. The winter, previously regarded as the off-season for anchovies,* was marked by an occurrence of these fish on an unusually great scale in all parts of Port Phillip Bay. Actually, the season was from April to September. A local firm commenced buying salted anchovies for use as fish-paste flavouring, and the hoop-net fishermen began to sell their surplus to it. However, they were soon joined by other men from the eastern shore of the Bay, who found they could catch up to 6 tons per haul by beach-seine. These were full-time fishermen who had not been interested in anchovies before and were not dependent on them for a livelihood. The fish available to them were larger than those in Hobson's Bay. This increased activity quickly glutted the limited market and buying ceased.

The winter of 1947 found the fish again abundant on the eastern beaches (from Black Rock to Mornington) but not at Hobson's Bay. Although the local demand for anchovies for fish-paste had eased (owing to the large stocks accumulated in 1946), the fishermen had been put in touch with similar firms elsewhere and good quantities were sold at prices up to 10d. per lb. There was also an enlarged demand for the fish as bait, largely for use as burley by professional barracouta fishermen. However, the anchovy fishermen complained that they could have caught much larger quantities if the demand had been greater. Probably the total production in 1946 was between 50 and 100 tons, and in 1947 somewhat over 100 tons. The occurrence was repeated in the winter of 1948, the fish being very abundant on the eastern beaches and in moderate quantities around the Hobson's Bay piers. As fish-paste manufacturers and market agents had accumulated stocks of anchovies in salt pickle and cold storage, there was practically no demand for the fish.

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* Apparently incorrectly, as far as the eastern shore is concerned, because the fish have appeared in each winter since, and it is now known that they were noticed there in several earlier years.

The beach-seine nets used measure up to about 100 fathoms and have bags of ½ in. mesh. Some operators use electric lamps at night to attract the anchovies. The net is "bunted up" in several feet of water to avoid bruising or dirtying the fish with sand. Anchovy shoals do not usually break the surface as do those of pilchards and other fish, but are generally seen lying as dense, dark patches some distance down.

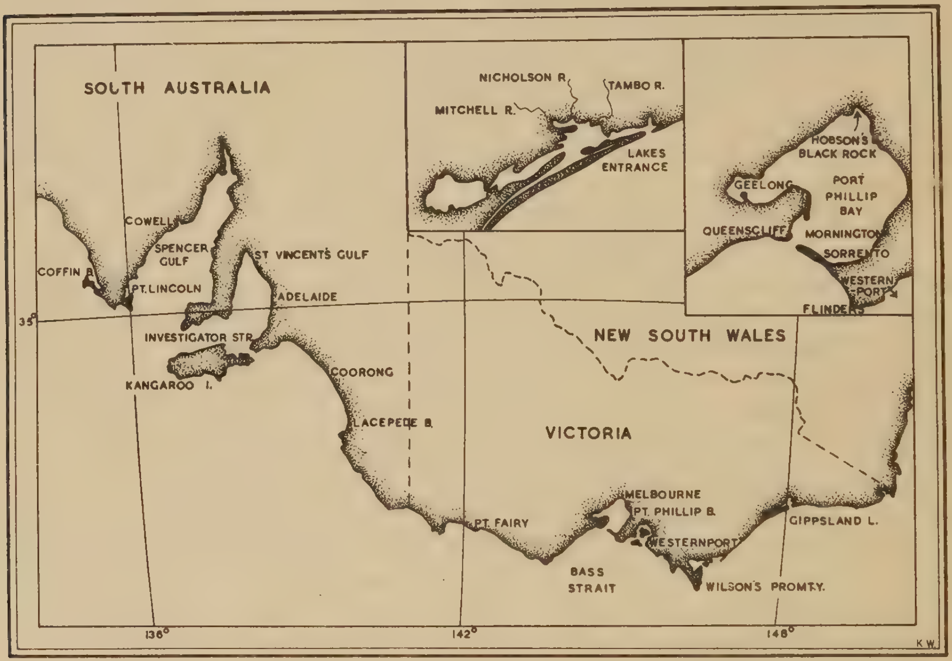
SOUTH AUSTRALIA
NICHOLSON R.
TAMBO R.
MITCHELL R.
LAKES ENTRANCE
HOBSON'S BLACK ROCK
GEELONG
PORT PHILLIP BAY
QUEENSCLIFF
MORNINGTON
SORRENTO
WESTERN PORT
FLINDERS
COWELL
SPENCER GULF
ST VINCENTS GULF
COFFIN B.
PT. LINCOLN
ADELAIDE
35°
INVESTIGATOR STR.
KANGAROO I.
COORONG
LACEPEDE B.
NEW SOUTH WALES
VICTORIA
MELBOURNE
PT. PHILLIP B.
PT. FAIRY
WESTERNPORT
GIPPSLAND L.
BASS STRAIT
WILSON'S PROMTY.
136°
142°
148°
K.W.

Fig. 1.—Victoria and South Australia, showing localities mentioned in text.

For paste manufacture, the fish are packed in small barrels with alternate layers of salt and allowed to "mature" for several months. Two firms have independently reported that the flavour is in general the same, but not of quite the same pungency or strength, as that of imported Mediterranean anchovies handled in the same way. A third company merely reported general satisfaction with the product.

Prior to 1946, small consignments of bait fish (clupeoids) were occasionally sent to the Melbourne market from other Victorian waters, when the Port Phillip Bay pier fishermen were temporarily unable to meet the demand. The only localities important in this way were Lakes Entrance (Gippsland Lakes) and Flinders (Westernport).

The broad features of bait fish occurrence in the Gippsland Lakes district are as follows. From about April to October, surface shoals often appear in the open sea up to 7 or 8 miles off Lakes Entrance. These shoals are more plentiful in some years than in others. They are most often seen on sunny days when there are light north-westerly winds. They may be found at least 20 miles from the Entrance in either direction along the coast. From about September or October some of these fish seem to move in very close to the shore and begin coming in through the Entrance, sometimes moving in and out upon the tides. As the summer begins, the fishermen cease to notice these shoals. The bait caught for the market is taken inside the Entrance with seines, generally between September and January, occasionally later.

The question of the identity of the fish is not easy, because most of the men speak of all clupeoids as "smig," and it is known that three species are to some extent involved, the pilchard and sandy sprat (*Hyperlophus vittatus*) as well as the anchovy. The only ones represented in the scanty samples actually taken offshore in winter (from barracouta stomachs) were the anchovy and sandy sprat, but a few pilchards have also been taken on the ocean beaches at the same time of year (July-August). From the fishermen's descriptions of the kinds of shoals seen it is almost certain that both pilchards and anchovies may occur on a large scale. The catches made by the beach-seiners a little later, just inside the Entrance, typically include all three species. An analysis of samples of these catches suggests that the pilchards predominate in September and the anchovies thereafter, increasingly so as time goes on. In the late summer and early autumn pilchards are absent or very scarce in the occasional catches that are made further up from the Entrance, towards the Lakes proper. The sandy sprat, which is at other times generally the least important of the three species, may be still present. It is concluded that there is winter and spring shoaling of all three species off and at the Entrance, after which the pilchards disperse seawards and the anchovies and sandy sprats lakewards. This is largely confirmed by one or two fishermen who are aware of the differences between the species, and who have studied their movements.

In the main Lakes waters, beginning several miles inside the Entrance, surface shoals are at times very numerous in fine weather, particularly in the warmer months. However, the fish may occur there in strength in winter also, as shown by Mack (1941, pp. 106-112) who studied the stomach contents of cormorants taken over the upper lakes waters from February to October 1939. He found that the anchovy first appeared in the cormorants' food in June, when it far exceeded all other (fish) species in importance; this remained so for the next three months, but in October these fish were no longer represented. The species even occurs in the rivers flowing into the lakes, according to material and information supplied by Mr. A. D. Butcher, Director of Fisheries and Game in Victoria. He found them there at all seasons of the year, mostly in the summer but some even in midwinter. These rivers were the Tambo, Mitchell, and

Nicholson. Summer salinity values of these rivers, at localities where the anchovies were located, were as low as about 2 parts per thousand at the surface, and would probably be even lower in winter because of rains.

At Flinders, fair quantities of bait were taken by beach-seine fishermen from July to September, 1945. These consisted of mixed anchovy, pilchard, and blue sprat, and the anchovy seemed to be most numerous on the whole, although pilchards were also well represented. The fishermen reported that they were operating on the fringe of a large body of shoals extending several miles seawards. At the end of September they stated that the fish were moving up into Westernport Bay.

The only other region from which there is any useful information is Port Fairy. Fishermen have reported seeing offshore surface shoals of small fish at various times from March to October, in different years, and have submitted specimens of anchovies taken from the stomachs of barracouta feeding among the shoals.

Thus, in Victoria, certain features of anchovy occurrence are to some extent common to widely separated localities. For Gippsland Lakes, Westernport, and Port Fairy, there is evidence of offshore winter shoals. For the former two places it appears that the fish move into the bay and inlet waters in spring, and for Port Phillip and the Lakes it is evident that in summer the fish are usually most plentiful in these more sheltered waters. One might take this to indicate a simple pattern of seasonal habitat phases of the life history, with winter occurrence in the outside waters and summer occurrences inside. However, there are exceptions to this, e.g. the winter runs of recent years in Port Phillip and the winter occurrence of 1939 in Gippsland Lakes, and the real life history is certainly more complex.

(*b*) *Maturity and Sex Studies*

In almost every case, at least part of each sample of fish measured was studied with regard to maturity stages. For each sex a series of condition stages was recognized. These stages were somewhat arbitrary and it was often difficult to decide which should be recorded.

Females

Stage 1.—Obvious immatures. Ovaries less than half length of body cavity, threadlike, glassy, or pale.

Stage 2.—This represents the beginning of the filling stage, and refers both to immatures commencing to mature for the first time, and "recovering spent" fish. The organs are usually at least half the length of the body cavity and larger in bulk than stage 1, but still comparatively small. The immature ovaries are white, straw-colored, or glassy, whereas the others are often distinctly bloodshot. However, the latter condition varies considerably and eventually disappears, so that it is sometimes impossible to say whether the fish is immature or not, especially in preserved material.

Stages 3 *and* 4.—Ovaries obviously filling, with pigmented discrete eggs. The stages are defined as occupying about half and two-thirds of the body cavity respectively.

Stage 5.—Ovaries at maximum size, almost filling the body cavity.

Stage 6.—This is retained for "running ripe" fish in most systems of this sort, but such individuals were not seen.

Stage 7.—Obvious spents. Organs generally still long but flaccid and reduced in bulk, generally very bloodshot. Succeeded by stage 2 ("recovering") with which there is overlapping.

Males

Stages 1 *and* 2.—These are troublesome. The smallest testis stage is an extremely small, rather leaf-like organ with a sharp outer edge, transparent or white, located approximately at the beginning of the posterior third of the body cavity. It would be natural to regard this as stage 1 and look for a slightly larger stage representing stage 2. This exists, but intergrades very closely with the smaller one, and in many cases semi-bloodshot organs have been found which were obviously recovering but which in respect of size alone would have been classified, on the above basis, as immatures.

Stages 3, 4, *and* 5.—These are distinguished mainly by bulk in the same way as the corresponding stages for females. The organs are white.

Stage 6.—As for females, this was not found.

Stage 7.—Criteria as for females.

In investigating length at first maturity, it is important to deal with data from the peak of the spawning season only. This is mainly to avoid any difficulty with fish whose organs showed no signs of filling at the beginning of the season but which might spawn before its close, or which might have spawned early and the gonads shrunk back to a pseudo-immature condition (especially males, see above). To some extent this procedure also reduces errors arising from the growth of the fish over the spawning period (see Section III (*d*)). It will be shown later that the spawning season is wide, but a preliminary appraisal of maturity records indicated that its peak would be from December to February inclusive, for Victorian waters as a whole. Therefore Table 1 refers to the data of those months for all available localities, indicating for each half-cm. length-group of fish the proportion that had spawned or obviously would spawn in the current season, i.e. all individuals at maturity stages except 1. In this study, references to half-cm. in each case mean the half-cm. below, e.g. 10.0 cm. = 100-104 mm., and 10.5 cm. = 105-109 mm., and all lengths are body lengths (i.e. excluding caudal fin) unless otherwise stated.

This Table does not include some unsexed fish in the length-group

TABLE 1

VICTORIAN ANCHOVIES MATURE AT SUCCESSIVE LENGTHS, DECEMBER TO FEBRUARY

Length (cm.)	Female			Male		
	Total	Mature	Per cent.	Total	Mature	Per cent.
5.0	4	4	100	2	2	100
5.5	29	26	90	19	19	100
6.0	94	93	99	63	62	98
6.5	131	131	100	69	68	99
7.0	62	62	100	37	37	100
7.5	24	24	100	36	36	100
8.0	21	21	100	36	36	100
8.5	33	33	100	33	33	100
9.0	21	21	100	31	31	100
9.5	20	20	100	17	17	100
10.0	19	19	100	7	7	100
10.5	4	4	100	1	1	100
11.0	1	1	100			

3.0 to 5.0 cm. There were 85 fish in the groups 3.0 to 4.5 cm. and none of them were mature. There were 25 unsexed fish in the 5.0 group and only 8 (32 per cent.) were mature.

TABLE 2

NUMBER OF FEMALE AND MALE ANCHOVIES TAKEN IN PORT PHILLIP IN DIFFERENT SEASONS BY LENGTHS

Length (cm.)	Dec.-Feb.		Mar.-May		June-Aug.		Sept.-Nov.	
	Female	Male	Female	Male	Female	Male	Female	Male
3.0	—	—	—	—	—	1	—	—
3.5	—	—	—	—	8	9	—	—
4.0	—	—	4	3	10	12	—	—
4.5	—	—	18	7	19	12	8	2
5.0	4	2	27	15	28	24	23	32
5.5	29	19	52	44	33	25	80	60
6.0	94	63	108	78	63	86	91	58
6.5	130	69	105	60	44	40	71	33
7.0	58	18	98	66	38	34	54	37
7.5	16	5	58	50	44	63	82	27
8.0	3	1	17	16	35	30	55	11
8.5	1	—	4	1	22	5	23	18
9.0	—	—	2	3	12	5	6	7
9.5	—	—	1	1	12	7	2	4
10.0	—	—	1	1	12	15	4	—
10.5	—	—	—	—	22	17	3	—
11.0	—	—	—	—	9	7	—	—
11.5	—	—	—	—	—	1	—	—
Total	335	177	495	345	411	383	502	289

Virtually all those of both sexes from 5.5 cm. to 6.5 cm. and all those at higher sizes are mature, during the period in question.

A curious situation is evident in respect of the sex ratio. Considering the data for Port Phillip first, and separately for the four seasons of the year, the position is shown in Table 2.

In the summer the females predominate by nearly two to one. In the winter there is almost parity, and intermediate ratios prevail in the other two seasons. It will be seen that this applies more or less irrespective of size of the fish. Nor does the effect arise out of selective sampling of material of certain years or year-classes only, because nearly every individual sample had the sex ratio appropriate to the season of collection. This also showed that the method of capture had no effect. For the other Victorian localities there is less material and it does not cover all seasons. However, the position may not everywhere be the same as at Port Phillip, because samples from Lakes Entrance showed the males predominant in both spring and summer, the actual ratios being 76: 98 and 68: 132. On the other hand, samples from the rivers entering Gippsland Lakes all had a preponderance of females in April, November, and December, the only months for which there are samples of reasonable size; the actual ratios were respectively 32 : 12, 65 : 28, and 59 : 41.

TABLE 3

PORT PHILLIP ANCHOVIES, 7.0 CM. AND OVER, AT MATURITY STAGE 5 BY MONTH AND SEX

Month	Female			Male		
	Total Fish	No. at Stage 5	Per cent.	Total Fish	No. at Stage 5	Per cent.
Jan.	24	2	8.3	7	2	28.6
Feb.	8	2	25.0	10	1	10.0
Mar.	19	—	—	12	—	—
Apr.	98	—	—	65	—	—
May	64	—	—	61	—	—
June	144	—	—	123	—	—
July	43	—	—	44	—	—
Aug.	19	—	—	17	—	—
Sept.	65	—	—	67	—	—
Oct.	34	—	—	25	3	12.0
Nov.	130	24	18.5	12	6	50.0
Dec.	46	16	32.6	7	3	42.9

It is now possible to investigate the spawning period more precisely. Since all fish at 7.0 cm. and over are mature, the simplest procedure is to ascertain the proportion of these at stage 5, for each sex separately, in each month of the year. This is not absolutely reliable, but stage 6 fish were not observed and there are difficulties about utilizing stage 7 observations because this passes very gradually into stage 2. More data would be available if the smaller fish were considered, but this would involve adjustment for immatures which might not be very precise for the non-summer months. For Port Phillip Bay the findings are shown in Table 3.

There is thus some spawning from November through February for both sexes, and some in October also for males at least. However, a few instances of stage 5 (and 4) anchovies have been noticed for smaller fish in March, and there is thus a small amount of spawning continuing into the autumn. A similar analysis of the data from the Gippsland Lakes region is presented in Table 4.

TABLE 4

PERCENTAGES OF GIPPSLAND LAKES ANCHOVIES 7.0 CM. AND OVER AT MATURITY STAGE 5 BY MONTH AND SEX

Month	Female			Male		
	Total Fish	No. at Stage 5	Per cent.	Total Fish	No. at Stage 5	Per cent.
Jan.	44	26	59.1	57	20	35.1
Feb.	—	—	—	—	—	—
Mar.	—	—	—	—	—	—
Apr.	32	11	34.4	12	5	41.7
May	—	—	—	—	—	—
June	5	—	—	4	—	—
July	4	—	—	4	—	—
Aug.	—	—	—	—	—	—
Sept.	34	—	—	34	—	—
Oct.	44	8	18.2	63	13	20.6
Nov.	65	20	30.8	28	21	75.0
Dec.	83	34	41.0	117	75	64.1

In this case, it is evident that there may be an appreciable amount of spawning for both sexes from October at least through April. Furthermore, a few stage 7 fish have been noticed in the September samples, which presumably represent very late spawners of the previous warmer period.

From Flinders and Port Fairy there are specimens only from July to September and March to September, respectively. The former samples contained a few spent fish in all months, apparently representing very late spawners like those just mentioned, and so a measure of reproduction may even extend into the winter months. The Port Fairy fish included a few that were at stages 4 and 5 in March and similarly in September, and in the latter case this seems to indicate some spawning, or its imminence, even before October.

For Victoria as a whole there is thus evidence of some reproduction at all times except in the three winter months, and possibly there is a little even then. However, considering the tabulated data above and bearing in mind that some little time may elapse before a full fish actually reproduces, it appears that the height of the spawning season is in the summer months.

Similar evidence, although incomplete, is provided by observations on anchovy eggs and larvae in plankton collections. The eggs were described by Dakin and Colefax (1933, p. 212, Plate vii, Fig. 2, and 1940, p. 203, Plate iv, Fig. 3), and the eggs and larvae by Blackburn (1941, pp. 75-79, Figs. 19-27). From late March to early December 1947, nine cruises were made around Port Phillip Bay and the "Discovery" N70 plankton net was used to make surface hauls at five stations in different areas. The plankton collections were examined for signs of anchovy stages, which were mostly eggs and early larvae. Later larvae are rarely taken in the smaller plankton nets, probably because they are strong enough swimmers to avoid them. The results are straightforward and need not be given in detail.

Not until early October were any anchovy stages taken at any of the stations, and then they were only fairly abundant at certain stations. By the end of the same month they were very abundant at all stations except that at Hobson's Bay, where they were in moderate numbers, and remained so up to the end of the period of investigation. During this latter (spring and early summer) period the numbers of eggs averaged several hundred per surface haul of 15 minutes. A few hauls made at the same season in earlier years gave similar results. Unfortunately the work could not be continued further into the summer, but as far as the data go they confirm the conclusions as to spawning time reached above. The best catch of anchovy eggs made in Port Phillip was in December 1943, when the smaller "Discovery" N50 net obtained over 3,000 eggs at the surface in 15 minutes.

A still smaller and generally less efficient net also yielded very good catches of eggs at the same period of the year at Gippsland Lakes. The field work was done by Mr. A. D. Butcher and the catches were examined by the author. There were 114 hauls made in different parts of the Lakes from September 1941, to December 1944, mostly for 10 minutes each at the surface. There were no anchovy stages taken in September and very few in (late) October, but generally the eggs were numerous in the collections of the three following months. The only other month of the year in which any work was done was June, when the catches were all negative. These results agree with those obtained from the study of maturity stages, as far as they go. Another series of 68 hauls was made in the rivers entering the Gippsland Lakes. Eggs were again found in the summer hauls, but the proportion of negative or small catches was high and only one yielded more than 100 eggs.

Practically no plankton collecting has been done in the open sea waters of Victoria, certainly too little to indicate whether egg production there is comparable with that in the more enclosed waters at the spawning season. There is definitely some spawning at sea in the immediate coastal waters (Blackburn 1941, p. 85). However, from the observations in Section III (*a*), it seems clear that anchovies are typically found inside the bay and lake waters in the summer, although they may move seawards in winter. Thus it is almost certain that most of the spawning takes place in these inshore localities, and there is positive evidence on this point from Tasmania (see Section IV (*a*)).*

(*c*) *Age-studies with Scales*

(i) *The Scales and Age-rings Described.*—The scales of this species (referred to as *Engraulis antipodum*) were described by Cockerell (1915, p. 36) and Peabody (1928, p. 145). They are like those of *Engraulis encrasicholus* as figured by Fage (1911, p. 15), and of two American species of *Anchovia* figured by Peabody, and there are some points of resemblance to the scales of other engraulids dealt with by the latter author. Peabody was puzzled because the types of scales found in this family seemed very diverse, and concluded that it could not be distinguished at all from the other clupeoid families in terms of scale formation (p. 143). However, this was mainly the result of regarding the Australian *Stolephorus robustus* (Ogilby), a dussumierid species, as an engraulid (under the name of *Anchovia robustus*). Leaving that form aside, the homogeneity of the family in scale structure is evident enough.

Considering the present species, the accompanying photographs (Plates 2-5) reveal a very different situation from that found in the clupeids. The half of the scale that is anterior (i.e. embedded) when on the fish is shown uppermost. Instead of having very fine transverse striae as in the clupeids, this portion bears more widely spaced striae which are disposed semi-concentrically, in a manner more reminiscent of salmonoid scales. They are parallel to the anterior and shoulder margins but then run obliquely towards the sides. On the posterior (free) half there is always some development of transverse fine striae, which are so close together that this part is practically opaque; this may cover almost the whole posterior portion or may be confined to an irregular band adjacent to the basal line.

The age-rings also have many of the characters of those of salmonoid scales, and are quite unlike those of clupeids. Most of the figures show that, in those sections wherein the striae are parallel to the scale margin on the anterior part, they may vary distinctly in their spacing, typically broadish bands of well-separated striae alternating with typically narrower bands of approximated ones. At a rule this does not apply to the areas nearer the basal line, where the striae are tending to become more transverse. However, other irregularities in arrangement are often noticeable here, similar to those encountered with percomorph scales; e.g. interrupted, branched, or fragmented striae, differences in direction of striae associated with zones of interruption, and such zones sometimes relatively wide and unstriated, forming translucent arcs like some rings found in clupeid scales. These latter zones, and also certain translucent arcs often found on the posterior parts of scales, are generally more or less continuous with the zones of approximated concentric striae in the more anterior regions, in such a way that a complete concentric ring can often be traced all round the scale. However, it is simplest to concentrate upon the apical and shoulder portions for scale-reading purposes. Much of this is very similar to the situation found by Fage (loc. cit.) for the European anchovy, although he spoke of the more coarsely striated half as the free part of the scale, i.e., presumably posterior; this must be a mistake because in the present species the same portion was carefully identified as being anterior, and in the scale pocket, when undisturbed upon the fish. Fage actually did not mention any approximation of parallel striae, but observed the other features mentioned above.

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* In November, 1948, offshore hauls were made with the N70 net at seven stations along the Victorian coast. One catch contained many anchovy eggs, but the others yielded few or none. This bears out the conclusion stated above.

As is shown below, these zones, represented in part by bands of closely approximated striae, are annual markings. It was found, from examination of scales from different parts of several individual anchovies, that those from the anterior part of the trunk, before the dorsal fin, had generally fewer striations than those from the rest of the body. Thus there were also fewer contributing to each annual ring, which was sometimes harder to detect. Apart from that area it did not seem to matter much where the scales were taken, but for the sake of consistency (for investigating the fish-length/scale-length relationship) they were nearly always selected from the ventral part of the middle of the flank, and always from somewhere in the general sub-dorsal region. Unfortunately a very large number of the specimens handled had no scales left at all. Esdaile (1912, pp. 7-10) and Bhatia (1931, p. 268) found, for two salmonoids, that the number of striae in each year zone was greater for scales from the middle of the trunk than from either end of it, but for the anchovy the only obvious diminution is anteriorly.

Permanent mounts of several scales (average three) were made from each fish, following the method of Graham (1929*a*). This involves applying pressure to the cleaned scale when placed on a drop of Mayer's albumen. Formerly this was done with the thumb, but lately the simple apparatus figured in Plate 1, Figure 2, has been used with great advantage. It was designed and made by Mr. W. J. Fletcher of the Division of Fisheries, C.S.I.R.O. The rubber stopper is placed over each scale and pressure is applied with the mounted spring door-stop. The mounted scales were examined with the apparatus described by Kesteven and Proctor (1941). Scale magnifications and intermediate lengths were recorded along the radius from the centre of the basal line to the anterior apex. Some scales in which the basal line was very uneven, making it difficult to decide from what point to measure, were discarded. In the case of intermediate lengths, measurements were made to the outer (anterior) edges of the zones of most closely approximated striae.

(ii) *The Fish-length/Scale-length Relationship.*—There were in all 1,396 scales from 442 Victorian fish for which full particulars were recorded as mentioned above. The data were grouped according to half-cm. intervals of fish-length (L), and mean values for L and the scale-dimension (S) were computed for each group. The scale-lengths, as it is convenient to call them, can be easily calculated from the magnification data, where the Kesteven-Proctor apparatus is used. The averages are given in Appendix A and are plotted in Figure 2.

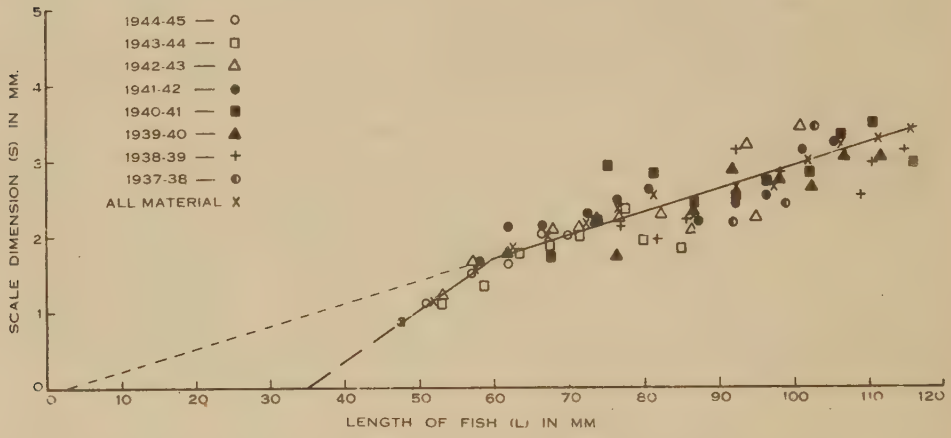

Fig. 2.—The fish-length/scale-length relationship for Victorian anchovies. The regression is based on the material of all year-classes combined (points plotted as X). The extrapolated line - - - - indicates that the relationship is practically constant in the upper part of the range. For further explanation see text.

The graph shows that the L/S relationship here is of the usual kind. The scale, being formed relatively late, grows at first faster than the fish (but for this the scales would not overlap as they do) and subsequently at more nearly the same rate (see Van Oosten 1929, p. 340). In this instance the later growth of fish and scale is at very nearly the same rate, although this is by no means the rule. In fact for clupeoids it is more often found that the scale continues to have a somewhat faster growth, so that the fish- and scale-lengths do not maintain a constant ratio, although their increments may. This has been shown for the Atlantic herring by Lea (1938, pp. 19-22), for the North American alewife by Huntsman (1919, pp. 79-82), and for various species of pilchards by Ramalho and Boto (1931), Murat (1935, pp. 129-132), Aikawa (1940, p. 90); Walford and Mosher (1943, pp. 13-14), and Blackburn (1949, pp. 27-30).

For most fish species studied from this aspect, the earlier phase of substantially faster scale growth has been of no practical significance, because it did not affect the range of size of fish and scale within which the annual rings were formed. The L/S relationship over this range was generally almost linear, whether of the type $L = B.S.$ (dimensions directly proportional) or $L = A + B.S.$ (increments directly proportional), where A and B are constants. Some authors have overlooked the first phase altogether, e.g. Lee (1920, p. 21), who believed that the relationship could be linear over the entire range of material. The point became important when instances were noted in which rings were formed at fish- and scale-dimensions falling in the first part of the range, e.g. the yellow perch study of Hile and Jobes (1940, pp. 108-110). With this anchovy the position is similar, and there is thus a problem in the calculation of the "intermediate" lengths of the fish, at the times of formation of the different rings.

One way to handle the matter would be to consider the L/S relationship over the whole range of material as representable by an exponential curve for which a single equation could be written. There is no doubt that this is really the proper way to express the relationship in all cases (see Huntsman 1919, and Marr 1943, pp. 163-165), and some authors have calculated intermediate lengths from scales from a formula of the type $L = b.S.^k$ where b and k are constants (e.g. Hile 1941, pp. 209-210; and Fry 1943, pp. 7-10). However, this procedure would involve a great wastage of the information so easily obtainable with the Kesteven-Proctor apparatus. Consequently, the position has been considered as expressible by two straight lines as shown in Figure 2. Regression equations have been calculated for these lines from the data of Appendix A. The one expressing the earlier stage of the relationship is

$$L = 34.9 + 14.5\ S \ldots\ldots\ldots\ldots\ldots \quad (1)$$

and the other is

$$L = 34.8\ S - 0.33 \ldots\ldots\ldots\ldots\ldots \quad (2)$$

The constant, 35 mm., in (1) is the intercept of the extrapolated line on the L axis. This is certainly very close to the size at which the anchovy commences to bear scales, because in a sample of 46 Victorian fish from 31 to 43 mm. there were only two below 35 mm. with any scales and only two above it with none. Thus the line can be extrapolated, and does represent the relationship from the first appearance of the scale up to the time the fish is of mean size 60 mm. In (2) the constant has no such biological significance, and is, in fact, not significantly different from zero. The recalculated equation is then:

$$L = 34.6\ S.$$

Therefore the L and S dimensions are in direct proportion for values of L over 60 mm.

The intermediate values of L (L_1, L_2, etc.), equivalent to the values of

S at the positions of the age-rings (S_1, S_2, etc.), were obtained as follows:

(1) First all were calculated on the basis of a direct proportion relationship; then wherever both L and L_n were at or over 60 mm. the latter value was not altered.

(2) However, where L was under 60 mm. an adjustment was necessary. The value of L_n finally adopted was calculated from the general formula

$$L_n = A + \frac{S_n}{S} (L - A)$$

which in this case is equivalent to

$$L_n = L_n^1 + 35 \left(1 - \frac{L_n^1}{L}\right)$$

where L_n^1 is the value calculated by direct proportions (see Blackburn 1949, pp. 28-30, and references there).

(3) An adjustment was also necessary where L was at or over 60 mm. but L_n (calculated from direct proportions) was less than 59 mm. The method was that of Hile and Jobes (loc. cit.) and consisted of adding to the L_n value as many mm. as were represented by the interval between the extrapolated regression line (2) and the regression line (1), for the appropriate ordinate level. Table 5 lists the "corrections" made at various intervals of L_n calculated by direct proportions (i.e. of L_n^1). This type of adjustment has the disadvantage that it takes no account of the actual value of S_n, which may vary for the same value of L_n. For instance, it could not be used in place of (2) where L also is under 60 mm., since occasionally the correction would make L_n higher than L.

Practically all values of L_1 and several of L_2 required adjustment on the lines of (2) or (3) above.

The L/S relationship could be importantly different for material of different year-classes. After the completion of the age-readings the means

TABLE 5

"CORRECTION" TO BE ADDED TO DIRECT-PROPORTION CALCULATED LENGTHS (L_n^1) WHERE FISH-LENGTH (L) IS AT OR OVER 60 MM.; ALL VALUES IN MM.

L_n^1	Correction	L_n^1	Correction	L_n^1	Correction	L_n^1	Correction
20-21	22	31-32	16	42-43	10	53	4
22-23	21	33-34	15	44-45	9	54-55	3
24-25	20	35-36	14	46	8	56-57	2
26-27	19	37-38	13	47-48	7	58	1
28-29	18	39	12	49-50	6	over 58	—
30	17	40-41	11	51-52	5		

of L and S were computed for scales of these year-classes separately, and the data are set out in Appendix B. It can be shown by simple plotting that the position, for any one of the eight broods represented, is very similar to that for all the material combined. This has been indicated in Figure 2. Even making no allowance for the fact that the separate year-class means are based on fewer observations, i.e. assuming that they do represent the L/S relationship properly for each individual brood, it is obvious that the errors involved in calculating L_n values from the overall formulae and correction table above, would mostly have been very small indeed.

As is shown (Tables 9, 10), Port Phillip Bay scales predominate in the material of the first three broods (i.e. those of most recent date) in Appendix B, and Gippsland Lakes scales in that of the last four. Thus an inspection of the S averages of that table also serves for an appraisal of possible differences between the two localities in respect of the L/S relationship. The data cannot be compared for all levels of L, but as far as they go they indicate that there is no such consistent difference associated with locality. Certainly there is no difference which could explain the difference in growth rate at these localities which is established subsequently.

(iii) *The Recognition of Annual Rings.*—For most scales from fish under 9.5 cm., the annual rings could be distinguished and counted quickly and confidently. However, in those from larger fish the proportion of doubtful ones was high, approaching half for material of 10.0 cm. and over. The scales from the younger ones were nearly as easy to read as those of brown trout (*Salmo trutta*), in many cases equally so. This follows from the similarity of the anchovy scale and rings to the situation in salmonoids. In all other types of Australian fish scales known to the writer, scale-reading is more difficult. The three published studies which deal with this matter in any detail (Kesteven 1942 on *Mugil dobula*, Cleland 1947 on *Sillago ciliata*, and Blackburn 1949 on *Sardinops neopilchardus*) all bear witness to considerable difficulties, mainly because of secondary or omitted rings.

Most fisheries biologists have adopted one or more of three criteria to recognize secondary rings. Such rings have been said to be:

(1) those which are relatively indistinct, incomplete, or thin;
(2) those which occur on a minority of scales from the same fish;
(3) those which occur on scales from a minority of fish in the population, as established by comparing material from fish of the same size and preferably from the same sample.

The author dealt with these points in the study of the Australian pilchard scales (loc. cit., pp. 31-36). The first criterion was unreliable in that case, the second was held to be mainly fictitious, and the third was used in various ways, as it was also for the detection of omitted rings. In the present anchovy material the proportion of rings which were suspect (because of appearance, or consideration of corresponding fish-lengths or increments between) was relatively small; and in nearly all these cases, after comparison with similar material about which there was no doubt, it had to be concluded that the rings were not secondary at all. Some rings were initially queried because of their L_n or associated T_n (increment) values, but it was found that these nearly all fell within the appropriate ranges of values established from indubitable cases, and thus the rings could not be distinguished from real annual ones. (The ranges of variation of L_1, L_2, etc. were mostly quite wide, whereas in the pilchard the author found less overlapping of age-groups in respect of fish-length).

Also, a ring that looked doubtful on one scale, because of the relatively small number of contributing striae, was often more obvious on other scales from the same part of the same fish. It was thus definitely useful to have for comparison more than one scale from each fish, but not because some showed fewer rings and could thus be supposed to yield a more reliable count of annual marks than others, as some authors have claimed for other material. As was argued by the author previously (loc. cit.), this would be opposed to the general belief that the rings register events in the life of the whole fish. At least in material from the same part of the body, the entire ring pattern is usually reproduced in every scale, but the individual rings may be more conspicuous in some than in others. There were no scales on which any rings appeared to be omitted.

Two of the scale photographs (Plate 4, Fig. 1; Plate 5, Fig. 1), illustrate rings (the first and second respectively) which are very thin, but which were much more conspicuous in other scales from the same fish, and could not be counted as secondary by reason of the associated intermediate length or increment values. In Plate 5, Figure 1 the other rings are rather thin also, and this was often so, but it does not apply in Plate 4, Figure 1. All such cases were particularly closely scrutinized, and a few were regarded as doubtful in the final appraisal. The fact that such inconspicuous annual rings could occur also meant that all scales had to be examined closely to see that none were overlooked. Actually, every scale was examined at least twice. Plate 3, Figure 2, shows a mark that is held to be a secondary ring, between the first and second. Plate 3, Figure 2 and Plate 4, Figure 1, actually depict Tasmanian anchovy scales, which are very similar to the Victorian ones in all respects. A few scales could be read for number of rings although intermediate lengths could not be recorded, owing to indistinctness of the rings along the axis of measurement.

The data of the following sections refer to scales which are all from different fish, i.e. only one scale is finally considered out of the several usually examined from each individual. This was naturally the one showing the ring-pattern best, and where there was no difference on this count the scale selected was that whose *S* measurement was nearest to the average for the appropriate category of *L* (see Appendix A).

(iv) *The Season of Formation of Annual Rings.*—To discover the time of the year when the rings are formed, the percentage of scales having the outer ring at the edge was determined, for each month, separately for material with 1, 2, 3, and 4 annual rings. There were very few scales in the collections with more than 4 rings. Early signs of developing rings were counted. The data are set out in Table 6.

TABLE 6

PERCENTAGES OF SCALES WITH 1, 2, 3, 4 ANNUAL RINGS, HAVING THE OUTER RING AT THE EDGE, FOR EACH MONTH

Month	Scales with 1 Ring			Scales with 2 Rings			Scales with 3 Rings			Scales with 4 Rings			All Scales		
	Total	Ring at Edge	Per cent.	Total	Ring at Edge	Per cent.	Total	Ring at Edge	Per cent.	Total	Ring at Edge	Per cent.	Total	Ring at Edge	Per cent.
Jan.	1	—	—	6	5	83	1	1	100	—	—	-	8	6	75
Feb.	5	2	40	24	23	96	3	3	100	—	—	—	32	28	88
Mar.	2	2	100	37	30	81	2	1	50	1	—	—	42	33	79
Apr.	—	—	—	4	2	50	9	4	44	15	7	47	28	13	46
May	7	4	57	11	7	64	3	3	100	1	1	100	22	15	68
June	1	1	100	2	2	100	7	4	57	7	6	86	17	13	76
July	—	—	—	5	1	20	3	3	100	2	2	100	10	6	60
Aug.	—	—	—	1	—	—	3	2	67	3	3	100	7	5	71
Sept.	—	—	—	2	1	50	—	—	—	—	—	—	2	1	50
Oct.	—	—	—	11	6	55	10	7	70	—	—	—	21	13	62
Nov.	27	—	—	28	6	21	14	4	29	17	—	—	86	10	12
Dec.	14	—	—	18	4	22	34	9	26	19	14	74	85	27	32

The table shows that a ring may occur at the edge in any month, but the percentage of these occurrences is least in November and December, and the general position is the same for all the rings. Very high percentages are most usual from May to August, and where they are recorded for other months they are generally based on very few observations. The indications thus are that all the rings are typically formed in the colder part of the year. This is actually better shown by the experience of scale-reading than it is in Table 6, because generally only a thin band of approximated striae (if any) is found at the edge in the summer and early autumn months, becoming broader in the winter and early spring and later being found inside the edge. This development has been followed for scales of the same year-class of fish through successive periods of the year. Some indication of these matters is found in the scale photographs. Plate 2, Figure 2 and Plate 5, Figure 1, represent November and December scales, and they are the only ones in which the outer ring is clearly inside the edge. Plate 3, Figure 2, Plate 3, Figure 1, and Plate 2, Figure 1, are of scales taken in January, February, and March respectively, and although the outer ring is fairly well developed at the edge in the second case, this is not so for the other two. Plate 4, Figure 1, Plate 4, Figure 2, and Plate 5, Figure 2, for June, October, and November respectively, show broad bands of approximated striae at the scale margin.

It follows that the rings on the anchovy scales are true annual winter rings. Since the general hatching season is the summer the successive rings are formed at average ages of ½, 1½, 2½, etc. years respectively.

It is shown later that the late spring and early summer is the growing season, whereas there is very little increase in length in winter (at least in the second and later winters of life, see Section III (*d*)), and it might be concluded that the scale-rings are formed in consequence of a seasonal lessening of growth rate. This may be so, and many scale readers working on other species, especially salmonoids, freely interpret the rings in this way. However, the matter has never been proved, and Graham (1929*b*, pp. 19, 43), produced arguments to show that variations in the spacing of striae or similar elements are not necessarily correlated with changes in growth rate of the fish. Wingfield (1940, p. 444) showed by experiment that growth rate could diminish without ring formation, if food supply was maintained. The author's length frequency data suggest a somewhat fast growth for the anchovy in the first winter of life, even though a ring is formed; the best evidence is that of June and July 1944, in Figure 4, but it is not claimed that this constitutes complete proof. The whole matter obviously requires further investigation.

(v) *Age-for-size.*—The general relationship between size and age of the fish, the latter indicated by the number of winter rings on the scales (including the margins), is shown in Table 7. This summarizes the results

TABLE 7

VICTORIAN ANCHOVIES RECORDED BY NUMBER OF ANNUAL (WINTER) SCALE-RINGS AND LENGTH OF FISH

Length-group (cm.)	0 Rings	1 Ring	2 Rings	3 Rings	4 Rings	5 Rings	6 Rings	Uncertain	Total
4.5	3	—	—	—	—	—	—	—	3
5.0	2	5	—	—	—	—	—	—	7
5.5	—	13	4	—	—	—	—	—	17
6.0	—	25	21	—	—	—	—	1	47
6.5	—	8	35	4	—	—	—	1	48
7.0	—	2	34	10	—	—	—	—	46
7.5	—	3	37	11	1	—	—	1	53
8.0	—	—	10	9	6	—	—	2	27
8.5	—	1	6	16	1	—	—	3	27
9.0	—	—	2	14	8	2	—	—	26
9.5	—	—	1	16	15	4	—	10	46
10.0	—	—	—	8	15	2	—	15	40
10.5	—	—	—	1	13	7	—	16	37
11.0	—	—	—	—	5	8	—	9	22
11.5	—	—	—	—	1	—	1	2	4
								Total	450

of age determinations based on the 1,396 scales of 442 anchovies referred to above, as well as an additional 12 scales from another 8 fish. The latter were those on which the number of rings was plain, although the material was not suitable for recording scale dimensions and intermediate lengths. Thus in all 1,408 scales were read from 450 Victorian fish.

Allowance must be made, in Table 7, for growth following ring formation. Scales with one ring or none were under-represented in the material, because those of small anchovies are more easily shed than those of large ones, and sometimes a hundred or more small fish were handled without finding any with scales.

(vi) *Size-for-age.*—The full range of values of the intermediate fish-lengths L_1, L_2, etc., was as follows:—

L_1 — from 42 to 77, a range of 36 mm.
L_2 — from 50 to 90, a range of 41 mm.
L_3 — from 63 to 103, a range of 41 mm.
L_4 — from 79 to 108, a range of 30 mm.
L_5 — from 97 to 112, a range of 16 mm.

This information amplifies that in Table 7. Obviously some fish of the 4.0 and 4.5 half-cm. groups can have one ring on their scales, and 2- and 3-ringed scales can occur on fish of the 5.0 and 6.0 groups respectively.

It is desirable to investigate the factors associated with the variation in growth of the individual fish. This matter has been discussed by Kesteven (1942, pp. 42-47) and Blackburn (1949, pp. 46-57), who showed that effects of sex, locality, brood, age-group, and relative size of fish should be considered in dealing with intermediate fish-lengths calculated from the scales. The anchovy material refers almost entirely to two localities, Port Phillip Bay and Gippsland Lakes, and for each of these the available data for L_1, L_2, etc., have been dissected by year-class, age-group, fish-length (in half-cm. groups), and sex, and the observations in each final category were averaged. The Gippsland Lakes material was mainly that from the rivers, as most of the other fish had lost their scales. These final means were mainly based on very few readings, but an inspection of them served to show how the data could be partly reassembled by ignoring certain factors.

It was decided firstly that variation between the sexes could be disregarded. Not all the fish whose scales were read were identified as to sex, and with those that were there was the difficulty that one sex often predominated, as indicated in Section III (*b*). Thus presentation of the averages of L_1, L_2, etc. by sexes, for material in each case homogeneous for locality, year-class, age, and size of fish, would not be worth the considerable space it would require. However, as far as the data go, they indicate that there is no considerable variation on this score. Neither sex has consistently higher intermediate lengths. There are, however, some data from Tasmania based on more satisfactory numbers of observations (see Section IV (*b*)), which indicate a slightly higher growth rate for females. If the females actually have a superior growth rate (as is more usual when there is any such difference, in teleost fishes) it cannot affect the general conclusions for Victorian fish, as shown later in this section. In any case the differences are extremely small in the Tasmania data.

Leaving this aside, the next factor to be investigated was that associated with fish-length. The data were incomplete and in places scanty, but there was ample evidence on the whole that this factor was important, in much the same way as it was for the Australian pilchard (Blackburn loc. cit.). That is to say, the larger fish of each age-group (for the same brood at the same locality) appeared to exhibit faster growth throughout life (higher L_n values for all the annual rings) than did the smaller ones. As with the pilchard, this effect is probably more apparent than real, and can be taken to indicate actual small differences in age, resulting from

TABLE 8

MEANS OF CALCULATED INTERMEDIATE LENGTHS (L_1, L_2, ETC.) AND OF FISH-LENGTHS (L) FOR CORRESPONDING SCALES, FOR SUCCESSIVE HALF-CM. INTERVALS OF L, BY AGE-GROUPS HOMOGENEOUS IN RESPECT OF YEAR-CLASS AND LOCALITY

Length-group (cm.)	Series A: Port Phillip, 1942/3 Class, 2-group						Series B: Port Phillip, 1941/2 Class, 2-group					
	L_1	L	n*	L_2	L	n*	L_1	L	n*	L_2	L	n*
5.5	53.00	59.00	1	—	—	—	46.00	58.00	1	55.00	58.00	1
6.0	53.00	62.75	12	—	—	—	45.00	62.00	1	56.00	62.00	1
6.5	55.10	67.35	20	—	—	—	52.00	66.50	4	64.00	66.50	4
7.0	55.08	71.77	13	66.00	74.00	1	53.54	72.46	13	68.60	72.70	10
7.5	55.00	77.00	2	70.00	79.00	1	53.58	76.69	26	72.89	76.73	19
8.0	63.00	82.00	2	72.00	84.00	1	55.00	80.75	4	75.00	81.00	3
8.5	—	—	—	—	—	—	56.00	86.00	1	72.00	86.00	1
9.0	—	—	—	—	—	—	54.00	91.00	1	86.00	91.00	1

	Series C: Gippsland Lakes, 1941/2 Class, 3-group								
	L_1	L	n*	L_2	L	n*	L_3	L	n*
8.0	44.00	82.00	1	62.00	82.00	1	76.00	82.00	1
8.5	52.00	87.33	9	65.50	87.50	10	76.75	86.75	4
9.0	51.78	92.78	9	66.80	92.70	10	85.50	92.50	6
9.5	55.25	97.00	12	72.25	97.00	12	88.57	97.00	7
10.0	54.75	101.00	4	73.00	101.00	4	92.00	101.00	4

	Series D: Gippsland Lakes, 1940/1 Class, 4-group											
	L_1	L	n*	L_2	L	n*	L_3	L	n*	L_4	L	n*
8.5	50.00	88.00	1	58.00	88.00	1	76.00	88.00	1	85.00	88.00	1
9.0	47.86	93.00	7	56.67	92.83	6	77.17	92.83	6	87.00	92.00	1
9.5	53.17	96.33	12	66.90	96.50	10	82.55	96.36	11	83.75	96.50	4
10.0	53.43	102.29	7	68.29	102.29	7	86.43	102.29	7	94.00	102.00	1
10.5	54.50	106.50	8	68.14	106.14	7	89.38	106.50	8	100.29	106.57	7
11.0	57.50	110.50	2	78.50	110.50	2	94.50	110.50	2	106.00	110.50	2
11.5	55.00	116.00	1	78.00	116.00	1	90.00	116.00	1	103.00	116.00	1

* n indicates number of observations, other units in mm.

the considerable spread of the hatching season, rather than size-for-age variation in the strict sense. In any case it means that growth compensation is not operative, which could also be surmised from the fact that the total range of even L_4 is not much less than that of L_1 (see above). The full data are copious and for many sections hardly worth presentation, but the means for successive fish-lengths for certain age-groups (homogeneous as to brood and locality in each case) are set out in Table 8, as examples. These were the cases in which there were reasonable numbers of individual observations, but the general fish-length/intermediate-length (L/L_n) relationship was evident in many other instances also.

In this section of the study, the age-groups 1, 2, 3, etc., refer to fish with the corresponding number of annual rings on their scales.

TABLE 9

PORT PHILLIP BAY

MEANS OF CALCULATED INTERMEDIATE LENGTHS (L_1, L_2, *etc.*) BY AGE-GROUPS, WITH MEAN FISH-LENGTHS (L) IN RESPECT OF CORRESPONDING SCALES, FOR MATERIAL OF FIVE YEAR-CLASSES SEPARATELY

	Age Group	L_1			L_2			L_3			L_4		
		Mean L_1	Mean L	n*	Mean L_2	Mean L	n*	Mean L_3	Mean L	n*	Mean L_4	Mean L	n*
A. Year-class	1	—	—	—	—	—	—						
1944-45	2	47.76	65.29	17	62.00	66.00	2						
B. Year-class	1	56.22	64.78	9	—	—	—	—	—	—			
1943-44	2	52.00	69.00	7	63.50	72.00	4	—	—	—			
	3	49.71	70.57	7	57.71	70.57	7	71.00	73.00	1			
C. Year-class	1	55.87	61.40	32	—	—	—	—	—	—	—	—	—
1942-43	2	54.86	68.20	50	69.33	79.00	3	—	—	—	—	—	—
	3	65.00	101.00	1	84.00	101.00	1	—	—	—	—	—	—
	4	49.25	86.25	4	61.75	86.25	4	72.50	86.25	4	101.00	103.00	1
D. Year-class	1	—	—	—	—	—	—	—	—	—			
1941-42	2	53.30	74.94	51	70.52	74.82	40	—	—	—			
	3	50.50	74.62	8	64.67	75.33	9	—	—	—			
	4	55.00	106.00	1	73.00	106.00	1	92.00	106.00	1			
E. Year-class	1	—	—	—	—	—	—	—	—	—			
1940-41	2	—	—	—	—	—	—	—	—	—			
	3	53.07	77.20	15	64.92	77.43	14	73.60	76.20	5			
	4	52.25	81.75	4	58.75	81.75	4	70.00	81.75	4			

* n indicates number of observations, other units in mm.

In the above-mentioned pilchard investigation the author (loc. cit.) determined regression equations to describe the relationship separately for L_1, L_2, etc., for each age-group of each year-class separately. The purpose of this was to determine the mean intermediate lengths corresponding to the mean of L for all material of each age-group, which seemed necessary because some scales yielded values for some intermediate lengths and not others, i.e., the means of L corresponding to means of L_1, L_2, etc., were different for fish of similar age. However these differences are mostly very small in the anchovy work (see Tables 9-11) and the labour involved in working out corrections would not be warranted. With the pilchard there were differences in means of L, for particular age-groups, up to 10 mm., but the final corrections to the L_n means were only of the order of 1 or 2 mm. at most.

Thus with this factor also neglected, there remain for consideration those associated with locality, year-class, and age-group. Tables 9 and 10 show the means of L_1, L_2, etc., and of the corresponding fish-lengths (L) for each age-group in each of five broods for Port Phillip Bay material, and in each of five broods for specimens from Gippsland Lakes. Other broods were represented by only very small numbers of observations.

TABLE 10

GIPPSLAND LAKES

DATA AS IN TABLE 9, FOR MATERIAL OF FIVE YEAR-CLASSES

		L_1			L_2			L_3			L_4			L_5		
	Age Group	Mean L_1	Mean L	n	Mean L_2	Mean L	n	Mean L_3	Mean L	n	Mean L_4	Mean L	n	Mean L_5	Mean L	n
A. Year-class 1942-43	1	—	—	—	—	—	—									
	2	56.91	84.54	11	71.90	84.10	10									
B. Year-class 1941-42	1	—	—	—	—	—	—	—	—	—						
	2	—	—	—	—	—	—	—	—	—						
	3	53.14	93.46	35	68.76	93.30	37	85.64	93.95	22						
	4	59.00	105.00	1	—	—	—	—	—	—						
C. Year-class 1940-41	1	53.00	68.00	1	—	—	—	—	—	—	—	—	—			
	2	—	—	—	—	—	—	—	—	—	—	—	—			
	3	55.50	98.00	4	68.75	98.00	4	87.50	98.00	4	—	—	—			
	4	52.71	100.00	38	66.38	100.18	34	84.61	100.28	36	96.35	103.00	17			
	5	50.00	92.00	1	58.00	92.00	1	70.00	92.00	1	82.00	92.00	1			
D. Year-class 1939-40	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	2	51.00	74.50	2	68.00	74.00	1	—	—	—	—	—	—	—	—	—
	3	55.00	87.00	2	73.00	86.00	1	80.00	86.00	1	—	—	—	—	—	—
	4	55.00	102.50	8	67.11	103.00	9	86.11	103.00	9	97.40	103.00	5	—	—	—
	5	53.36	104.71	14	66.58	104.50	12	78.17	103.50	12	93.29	104.71	14	103.00	110,00	3
E. Year-class 1938-39	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	2	59.00	85.00	1	77.00	85.00	1	—	—	—	—	—	—	—	—	—
	3	52.40	82.20	5	67.17	83.00	6	79.00	86.33	3	—	—	—	—	—	—
	4	53.00	98.00	1	65.00	98.00	1	85.00	98.00	1	—	—	—	—	—	—
	5	52.00	110.00	2	58.50	110.00	2	75.50	110.00	2	97.00	111.00	1	106.00	110.00	2

These Tables reveal that there is an important and consistent variation by age-groups. The intermediate length averages are progressively lower for fish of increasing age, which is the usual finding where there is variation associated with age-groups, and is known as Lee's Phenomenon. Apart from a few figures based on one or two observations only, there are no exceptions to this trend in any sections of these tables. It is necessary to consider the significance of the phenomenon to decide which intermediate length values are the most reliable.

Several explanations of this variation have been suggested in the literature, but no single one seems to have gained general acceptance. Kesteven (1942, p. 44) summarized the possibilities briefly under four headings. One of these, which involves a possible confusion of other effects producing variation, can be rejected in this case, as it is the purpose of this section to identify and separate these effects. Another possibility is that there is selective mortality in the population, causing the younger age-groups to be represented by relatively large fish, or (more likely) the older groups to be represented by relatively small ones. The most likely cause of any such mortality would be fishing operations, and since the anchovy is very little fished, this hypothesis can also be disregarded.* The third suggested explanation involves actual changes (e.g. shrinkage) in the scales with increasing age, for which no convincing evidence has ever been brought forward for any species. The fourth possibility is in Kesteven's words "technique, as a consequence chiefly of special sampling, by nets." It has been argued that the fish in the catch could comprise relatively large individuals from younger age-groups, and/or relatively small individuals from the older groups, if some form of net or other gear selection was operating. Then, if the scales of larger fish yielded higher L_n values than those of smaller ones of the same general age (as just shown for the anchovy, for instance), Lee's Phenomenon could be accounted for.

In the present case, the explanation could not be quite of this type because the fine mesh of the nets used in the fishery allows hardly any fish to escape, but what is certainly the real situation could be called a case of "special sampling" nevertheless. As mentioned above, small fish lose their scales (during netting and market handling) more easily than large ones, and thus, in almost every sample handled, it was only from the larger individuals that scales could be obtained for age-studies. The author was conscious on most occasions that he was, unavoidably, selecting his scale material in this way. A comparison of the data of Table 7 and those in the first paragraph of this section shows quite plainly that, in the 1-group particularly and also in the 2- and 3-groups, the scales of the smaller fish were not available for study. It follows that the most reliable L_n averages will be those obtained from the scales of the oldest fish, except insofar as there may be less material available for the senior age-groups.

The data of Table 9 show also that the means for the 1944-45 and 1943-44 brood fish of Port Phillip are lower than those for the same age-groups in other broods, for which the values are more or less alike. This could, however, be a sampling error. In any case, since these two broods are not represented in the Gippsland Lakes material, and since it is required to compare the data of the two places for possible locality variation in growth rate, it is convenient to ignore both year-classes in the final phase of this part of the study. There is no noticeable L_n variation by year-classes for the Gippsland Lakes material. Table 11 compares the various L_n means for the separate age-groups for Port Phillip and Gippsland Lakes scales, for the same five consecutive broods of fish, i.e. including the scanty data for 1939-40 and 1938-39 brood scales from Port Phillip.

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* Selective mortality due to predators has also been suggested. The anchovy has many natural enemies, but the extent to which they reduce the stocks is unknown. The predation might not be selective at all. If the tendency was to select the smaller fish available, the conclusions of the following pages would not be affected. If the larger ones were selected and the mortality from this cause was considerable, then the intermediate length data from the younger age-groups would, other considerations apart, be more reliable. In any case, however, the scale-selection effect mentioned here must operate to some extent and is probably the most important cause of Lee's Phenomenon in this material.

This Table shows Lee's Phenomenon very strikingly, the sole exception being one entry based on only one observation. It also shows that the L means are very uniform within the same age-group at each locality, so that any corresponding adjustments of the L_n means would be negligible. It is also obvious that the Gippsland Lakes L_n means are consistently a little higher than those for Port Phillip.

The most reliable L_n averages that could be obtained would be those for the oldest age-group available for each locality, assuming adequate numbers of observations (see below). This means the 4-group for Port Phillip and the 5-group for Gippsland Lakes and, because the evidence of Lee's Phenomenon does not end with the 4-group, the Port Phillip averages must be regarded as slightly high relative to the others. Omitting the single L_4 observation for Port Phillip, and rounding all figures, the final comparison of growth rates — intermediate lengths and increments (T_n values) — is as follows:

Port Phillip Bay	Gippsland Lakes
L_1 — 50 mm. or slightly less	L_1 — 53 mm.
L_2 — 62 mm. or slightly less	L_2 — 65 mm.
L_3 — 74 mm. or slightly less	L_3 — 77 mm.
	L_4 — 93 mm.
	L_5 — 104 mm.
T_1 — 50 mm. or slightly less	T_1 — 53 mm.
T_2 — 12 mm. (approximately)	T_2 — 12 mm.
T_3 — 12 mm. (approximately)	T_3 — 12 mm.
	T_4 — 16 mm.
	T_5 — 11 mm.

The actual figures for L_1, L_2, and L_3 are 3 mm. higher for Gippsland Lakes in each case. Possibly the real difference would be about 5 mm. This indicates a real and consistent difference in the growth rate of anchovies in these two localities. Females predominated greatly in the Port Phillip material, and so the above difference might be suspect (as a locality difference) if it could be shown that male anchovies grow faster. However it was noted earlier than there is no evidence for this, and in fact, if there is any such difference between sexes, it is probably in favour of the females (Tasmanian data, see Section IV (*b*)). The L_n averages are the sizes attained in winter and thus L_1, L_2, L_3, etc., are the lengths attained at ages of about ½, 1½, 2½, etc., years. The general scheme of average growth rate in Victoria would thus be as follows:

Length at 1st winter (age ½ yr.) — about 50 mm. (2.3 in. total length).
Length at 2nd winter (age 1½ yrs.) — about 62 mm. (2.9 in. total length).
Length at 3rd winter (age 2½ yrs.) — about 75 mm. (3.5 in. total length).
Length at 4th winter (age 3½ yrs.) — about 90 mm. (4.2 in. total length).
Length at 5th winter (age 4½ yrs.) — about 102 mm. (4.7 in. total length).

It will be noticed that T_4 is greater than T_2 or T_3, which are equal, considering the above mean values for Gippsland Lakes fish. Usually, but not always in fish species, the values of the successive increments decline with increasing age. Possibly the finding here is merely the result of irregular scale sampling, but the increased growth between the third and fourth rings was certainly obvious in many of the individual scales read, for instance the one in Plate 5, Figure 2. In others again, T_3 was larger than T_2 or T_4, as would also be the general finding above if the Gippsland Lakes L_n means were those calculated from 4- and not 5-group scales (the former contributing more observations; see Table 11). The stage at which this increase takes place would be in the third (or in some cases the second) spring and summer after hatching, and it is probably related to some change in the life history. Further speculation seems unwarranted at present.

In this study of L_n variation, the effects associated with relative size in the age-group, with age-groups, and with localities, were all found to be important. There is possible but not certain variation between year-classes, and reference is also made to some later evidence which suggests

TABLE 11

DATA AS IN TABLES 9 AND 10, FOR MATERIAL OF PORT PHILLIP AND GIPPSLAND LAKES, FIVE YEAR-CLASSES (1938-39 TO 1942-43) COMBINED

	Age Group	L_1			L_2			L_3			L_4			L_5		
		Mean L_1	Mean L	n	Mean L_2	Mean L	n	Mean L_3	Mean L	n	Mean L_4	Mean L	n	Mean L_5	Mean L	n
A. Port Phillip Bay	1	55.87	61.40	32	—	—	—	—	—	—	—	—	—			
	2	54.07	71.60	101	70.42	75.11	43	—	—	—	—	—	—			
	3	52.23	78.23	26	65.60	78.24	25	75.67	79.00	6	—	—	—			
	4	49.91	86.73	11	61.91	86.73	11	73.82	86.73	11	101.00	103.00	1			
B. Gippsland Lakes	1	53.00	68.00	1	—	—	—	—	—	—	—	—	—	—	—	—
	2	56.21	83.14	14	72.00	83.25	12	—	—	—	—	—	—	—	—	—
	3	53.35	92.35	46	68.65	92.25	48	85.04	93.46	30	—	—	—	—	—	—
	4	53.23	100.48	48	66.50	100.71	44	84.91	100.76	46	96.59	103.00	22	—	—	—
	5	53.00	104.58	17	64.93	104.40	15	77.27	103.60	15	92.82	104.31	16	104.20	110.00	5

some variation between sexes. A neglect of any of these factors, e.g., any attempt to compare growth rates simply between localities without first attempting to identify other types of effects (as is sometimes done) could obviously produce inexact results.

(*d*) *Length Studies*

All the anchovies in the samples, from Victoria and elsewhere, were measured for body or standard length. This is the length from the snout tip to the commencement of the caudal fin, as shown with the scales removed. All references to length in this study refer to this measurement unless the contrary is stated. Many fish were also measured for total length, i.e., from the snout tip to the end of the longest caudal rays when these are held parallel to the long axis of the body. The following conversion formula was established:

Total length = 1.18 x body length.

The number of Victorian fish measured, excluding larvae, was 23,582. The total is dissected by localities and years in Table 12, and in more detail (by samples) in Appendix C.

TABLE 12

LOCALITIES AND YEARS OF CAPTURE, FOR MEASURED VICTORIAN ANCHOVIES

Year	Port Phillip	Flinders	Gippsland Lakes*	Other**	Total
1937	82	—	—	—	82
1938	—	—	12	—	12
1939	—	—	—	13	13
1940	—	—	—	—	—
1941	19	—	20	—	39
1942	143	—	10	—	153
1943	1,590	—	—	—	1,590
1944	4,858	—	685	9	5,552
1945	3,080	1,533	425	21	5,059
1946	11,082	—	—	—	11,082
Total	20,854	1,533	1,152	43	23,582

* Including the rivers and offshore waters, with totals of 272 and 24 respectively.
** All Port Fairy except those of 1939, from off Wilson's Promontory.

From an analysis of length frequency data, an attempt was made to investigate the age-composition of the populations and the general growth rate of the species, as a check on scale-readings. Under ideal conditions there could be drawn separate length frequency polygons for successive months of, say, one particular year, from which to trace the progression of age-group modes with time. This was not entirely possible in this case, largely because of supply fluctuations which caused many months to go unsampled. However, a series of polygons representing the data of successive months, irrespective of years, has been prepared, as Figure 3. The panel for the first month (October) is repeated at the bottom. The frequencies were smoothed by a moving average of three.

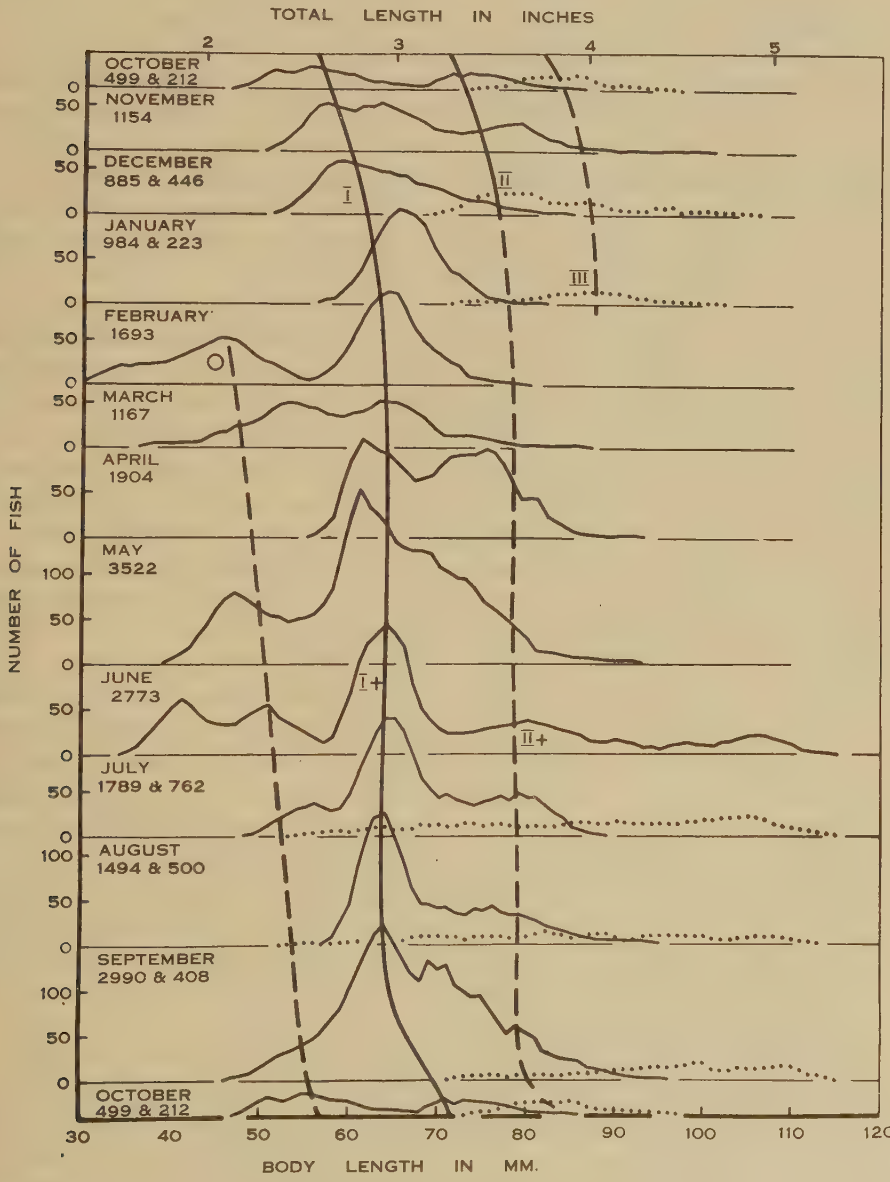

Fig. 3.—Length frequency polygons by months, all years combined, for Victorian anchovies. Unbroken curves are for Port Phillip Bay, dotted ones for all other localities combined. The numbers of fish are shown separately for Port Phillip and for other places combined, the former first.

Separate polygons have been constructed for material from (*a*) Port Phillip and (*b*) all other Victorian localities combined. There are no non-Port Phillip polygons for November, February, March, April, May, and June because these were represented by only 93, 13, 9, 44, 1, and 17 observations respectively. The numbers of observations in each month are shown separately for (*a*) and (*b*). The lines joining the modes are considered to represent the general pattern of their progression, the scheme as indicated by broken lines being more hypothetical. In some cases, e.g., for April, the fit of the modes to the lines is not especially good, but this is not surprising in view of the rough sampling and grouping of the data of different years, and the long spawning season. The largest fish in this Victorian material measured 121 mm. body length, or 5.6 inches total length, and was taken in Port Phillip.

As the main spawning season in these waters is the summer, one might expect to encounter an O-group of fish in the late summer and autumn, and this is the status of the first main group in the February graph, with a mode at 47 mm., since many of these fish were obvious post-larvals. The first modes for March and May seem to have the same significance, also the first two for June. There is some variation in these modal sizes, but this would be expected for fish only a few months old, which could have been hatched at any time over a spawning season of several months. These small fish are not often caught except when larger ones are unavailable. The line purporting to represent the progression of this group must be regarded as only approximately placed.

What is obviously the same group at a later stage is next important in the October material, with modal length about 55 mm. This is the order of size at which the species enters the general commercial catch. The group can easily be identified in each of the next few months, at rapidly increasing modal lengths, indicating fast late spring and early summer growth. At the age of one year most of the fish would be about 60 to 65 mm. long. From about January or February the growth rate of the (now I-) group is diminished, the general size throughout the winter being of the order of 65 mm. Between September and October there is renewed growth and this continues for the next few months as was the case a year before, so that the fish are of modal length between 75 and 80 mm. at approximately 2 years of age.

The material considered so far refers almost wholly to the Hobson's Bay catches, but fish of over 2 years are rarely caught here and it is therefore necessary to consider material from other places. Indeed, fish of much over one year are not common at Hobson's Bay, although the II-group* fish represented in the October graph were taken there; the

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* The I-, II-, etc., groups are those of fish which have completed 1, 2, etc., years of life; they are not, therefore, equivalent to the 1-, 2-, etc., groups recognized for the purpose of scale studies.

November ones were from Geelong. On the other hand, the O- and I-group anchovies do not seem to occur importantly outside Hobson's Bay, and are certainly not caught. The growth of the II-group can be followed further only with more difficulty. It is represented in the non-Port Phillip (Gippsland Lakes) material of December and then not clearly, in these samples, until the winter. Most of the latter fish were from the 1946 winter run on the eastern beaches of Port Phillip. Again there appears to be little winter growth.

From this stage, representing about 2½ years of age, anchovies are not so conspicuous in Port Phillip Bay. However, they obviously do occur and might well be under-represented in these samples. There are some considerably larger fish in the material of November (from Geelong), June (from Queenscliff), and August and September (from the more southerly eastern beaches). On the assumption that the growth rate of the other Victorian fish is similar to that at Port Phillip, the II group is traceable through October, December, and January, and it appears that there is again increased growth at this season, so that at 3 years old the average length is about 85 to 90 mm. The samples in these months refer to the Gippsland Lakes, mostly the Entrance. Beyond this point the data are not useful. The July, August, and September material is from Flinders.

There are also some data of the same kind that serve to confirm the above picture of growth rate in part, for several successive months of the same calendar period. The two best series available are shown in Figure 4, being one for ten months of 1943-44 for Port Melbourne and one for nine months of 1946 (with one break) for all Port Phillip. These confirm most of the points made above regarding growth in the first 2½ years of life.

Two general conclusions as to anchovy growth rate in Victoria are indicated, as follows:

(1) The fish attain average lengths of about 60 to 65, 75 to 80, and 85 to 90 mm. at the ages of 1, 2, and 3 years (i.e., at the first, second, and third summers after hatching), but there are larger fish at greater ages.

(2) Apart from the first few months of life, in which the position is not clear, the growth rate is fast in the spring and summer and slow in the autumn and winter, probably at all ages.

A comparison of these average lengths at successive summers with the average lengths at successive winters, as determined from scale-reading (last section), reveals good agreement, bearing in mind the second conclusion above. The average length at the first summer after hatching, for example, is considerably more than that at the first winter and practically the same as that at the second winter. Comparing these data also with those of Section III (*b*) it is evident that the fish are almost all mature at the age of one year and all mature at two years.

It is desirable to summarize the general position as to age-composition

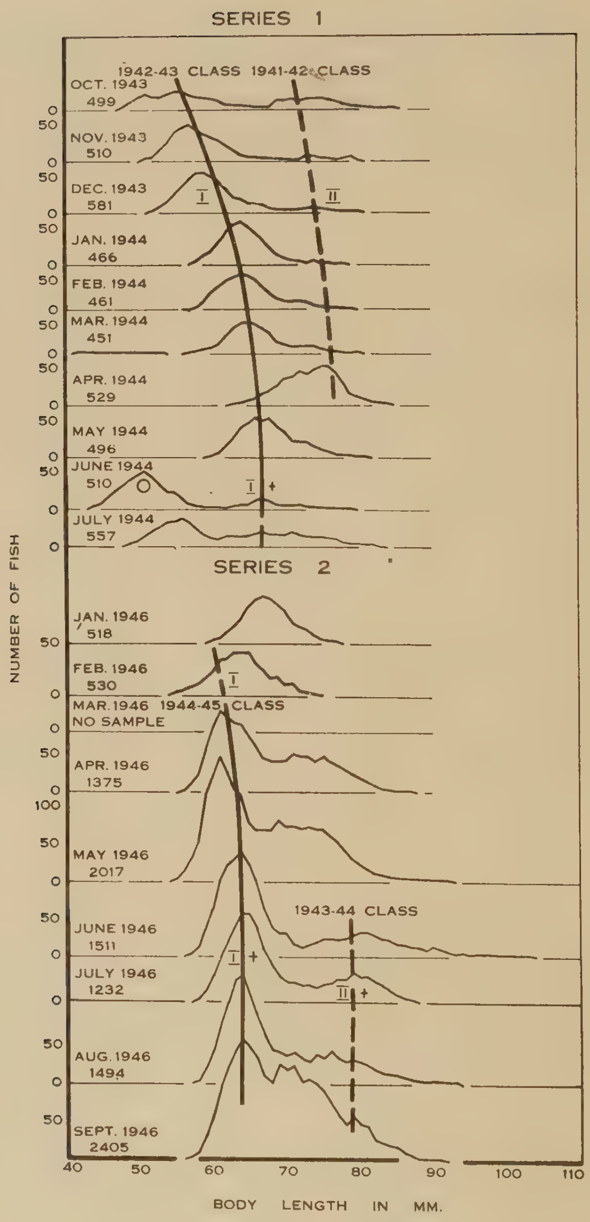

Fig. 4.—Length frequency polygons by months, two series for Port Phillip Bay anchovies. In Series 1 all samples are from Hobson's Bay. In Series 2, the January and February fish, and those in the younger age-group for the later months, are from Hobson's Bay; the rest from the eastern beaches and Geelong. For further explanation see text.

of the stocks in the different localities, as revealed from the combined scale and length frequency studies.

In Port Phillip the Hobson's Bay pier fishery operates mostly on fish about one year old, but also takes some that are younger and older (but usually not above two years). Elsewhere those caught are mostly about two (summer) or two and a half (winter), but there are some older fish in the southern portion of the Bay.

At Gippsland Lakes the position seems also to differ from place to place. There are only 24 specimens representing the outside winter shoals, and they range from 52 to 95 mm. The fish just inside the Entrance in spring and summer seem to be mostly about 3 and 4 years old. Local observers say smaller fish occur, but more sparsely. The specimens found in cormorant stomachs in winter by Mack (1941) were, according to advice from him, mostly about 3½ to 4 inches total length, equivalent to about 75 to 85 mm. body length, and thus probably about 2½ years old. The birds were taken and had been feeding over the upper lake and the river waters. Finally, the examples from the rivers were mainly of 4-year and older fish, though with some younger, down to about one year.

At Flinders the range in the winter samples is wide, including a few fish under one year and some probably over four. Most of the anchovies would be over two years of age.

At Port Fairy the range in size of the 30 specimens (from the winter shoals) is similar, from 49 to 115 mm. Reports from fishermen indicate that the larger sizes are most commonly taken. The 13 (summer) specimens from Wilson's Promontory were postlarvals.

(*e*) *Statement of Life History*

The following statement of the life history of the anchovy in Victoria is compiled from the evidence of the preceding sections. Some parts of it are better illustrated by the data of some localities than others, and there may actually be some differences in the position in different places. However, a certain basic pattern of events is evident throughout.

Spawning takes place mainly from late spring to about early autumn, in the bay and inlet waters. The postlarvae acquire their scales when they are about 35 mm. long, and in Port Phillip they are apt to be seen in Hobson's Bay from about February onwards. As they have not been noticed elsewhere, there is probably a general concentration of these very small stages to the head of the Bay. This must take place some time during the first year of life, because yearling fish definitely do not occur conspicuously except in the upper waters. At about six months of age these fish measure about 50 mm. average body length, but there is fast growth during the spring and early summer which brings them to about 60 to 65 mm. body length (about 3 inches total length) at the end of their first year. Practically all of them are then mature. These yearlings provide the bulk of the catches that are made around the Hobson's Bay piers, and they do not usually occur importantly elsewhere.

During the autumn they tend to disappear, although some remain, and occasionally they are abundant throughout the winter (as in 1946). There is very little growth at this time, so that the mean length at about 1½ years of age, in the second winter of life, is still not much over 60 mm. Growth rate increases again in the spring and at two years the average size is 75 to 80 mm. body length (about 3½ inches total length). At this stage not many fish are still in the extreme upper part of Port Phillip Bay, but they are abundant nearer the sea, at Geelong, and make up the bulk of the catches there. Doubtless they are also present elsewhere. By the following winter the average age is 2½ years, although the size has not increased. At this time, in at least some years and probably to some extent in every year, they occur in conspicuous shoals off the eastern bay beaches. Although the catches made there are mostly of this age-group, there may be an admixture of younger fish towards the northern (upper) part of the bay, and of older ones towards the southern (seaward) part.

Older fish also occur in Port Phillip. They are not prominent in the catches, but these may not be representative of the population. There are fish taken on the south-east beaches, at Geelong and elsewhere, which are 3 and 4 years old and probably more. Occasionally such fish occur in Hobson's Bay (they did so in 1948) but this is most unusual. On the whole, it is obvious that the fish under two years of age are concentrated in the upper part of the Bay and the older ones in the middle and lower reaches. There is no positive evidence that the latter pass out to sea or return, but the matter has not been investigated adequately. Judging from occurrences elsewhere (see below) they might well do so in the winter. Some large fish have been taken just inside the Heads in June.*

At Gippsland Lakes very few anchovies under about 2½ years of age, or the equivalent sizes, have been noticed, possibly because the upper waters (other than the rivers) were not fished. However, readings of scales from older ones show that the growth rate in earlier life is very similar to that at Port Phillip (actually very slightly faster). These scales were mostly of river fish, but there were some (also length frequency data) from lake individuals, and there was no suggestion of any substantial difference in growth rate. The evidence from cormorant stomachs shows that there are fish which are probably 2½ years of age (judged from their size) in the upper lakes waters in the winter, disappearing in the spring. Through the spring and summer there are also occurrences at the Entrance, which mostly consist of fish at or approaching 3 and 4 years. The average body length at 3 years is about 85 to 90 mm. (about 4 inches total length).

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* In November, 1948, medium-sized and large anchovies were found in barracouta stomachs at many places along the Victorian coast. At Port Phillip the occurrences were just inside the Heads. There was little evidence of widespread spawning at sea (see footnote at end of Section III (*b*)) and it may be concluded that the spawning migration into the bays was then taking place, or was imminent.

Some at least of the Entrance fish are known to have come in from the sea, where anchovies school during the winter (evidence from barracouta stomachs). Some may also be derived from the upper lakes waters, since the time of their disappearance there coincides with the arrival of fish of the expected size at Lakes Entrance. However, the former may go into the rivers instead and have nothing to do with the Entrance shoals (see Section VII, which shows that the river and Entrance anchovies are separate populations). There is no reliable information about the age composition of the stock at sea, but the fish there are not likely to be abundant under 2½ years, because they definitely move inside the Entrance after the winter, and relatively few of those caught there then are more than a few months under 3 years. For lack of evidence as to the whereabouts of the younger fish, it is reasonable to suppose they are located further up from the sea, as they are at Port Phillip during at least the first two years of life. The Entrance fish move further up into the lakes system during the summer and autumn, as noted in Section III. (*a*).

The evidence from Westernport, although limited, largely confirms that for the Lakes. Shoals of anchovies may occur at the entrance and thence seawards from July to September, after which they seem to pass up into the bay proper. A length frequency analysis of samples taken on the Westernport beaches (see Fig. 3; hardly any of these fish had any scales when received) indicated that some fish at all ages, but probably mostly over 3 years, participate in the winter seaward movement. The scanty data from Port Fairy also show that anchovies occur at sea mainly in the colder months, though nothing is known of their occurrence in inshore waters. Practically all sizes, and presumably all ages, are represented in this phase, but with larger fish more abundant.

All these observations can be accommodated in the one general scheme of life history. The anchovy in Victoria is primarily an inhabitant of bay and inlet waters. These constitute the main spawning and nursery areas and the great majority of individuals up to 2½ years of age remain inside them. At this earlier stage there is, however, some localization of age-groups, the younger fish being concentrated in the upper reaches and the older ones nearer the sea. Some fish at 2½ years, a few that are younger, and probably the majority of older ones, make a winter migration out to sea and return again during the spring. In other words, with increasing age there is a tendency for the fish to develop a two-phase life involving both the bay and open sea waters, in the warmer and colder parts of the year respectively.

As was indicated earlier (Section III (*a*)) there are natural fluctuations in abundance of anchovies in Victorian waters. On the whole these do not seriously affect the operatives in the small fishery that exists at present, and do not seem to be as frequent or violent as in some other species, such as the pilchard in the same waters. For instance, an examination of the records of bait catches of four Hobson's Bay hoop-netters to their market agent, over a period covering five consecutive seasons from October to May inclusive, yielded the following rounded figures (Table 13) when reduced to a catch-per-man-per-season basis.

TABLE 13

MEAN CATCH PER MAN BY HOOP-NET AT PORT MELBOURNE FOR OCTOBER-MAY INCLUSIVE, IN FIVE CONSECUTIVE YEARS

Year	Anchovy (lb.)	Pilchard (lb.)
1937-38	2,360	4,660
1938-39	1,360	190
1939-40	4,460	810
1940-41	2,640	1,390
1941-42	4,660	2,910
Mean	3,100	1,990

Although the total output of the bait fishery is small, it is obvious that the catch is liable to vary according to the supply of fish, but not to a particularly marked degree for the anchovy. General observations made more recently, and reports from fishermen in respect of earlier years, confirm this conclusion. The most conspicuous anchovy fluctuations in the last five or six years have been favourable to the fishermen. Because of these things, and because the fishery is small and not definitely assured of future expansion, the question of natural fluctuations has not so far received much attention. The foregoing statement of the life history would provide a basis for any future work on abundance fluctuations. Fluctuations in availability, such as the unusual 1946 winter run of 1½-year fish, would constitute a greater problem.

IV. THE ANCHOVY IN TASMANIA

(a) *Distribution, Length, and Maturity*

There is no commercial anchovy fishery in Tasmania, and the specimens studied were all obtained in the course of special research activities. There were only 2,202 fish available for measurement, and 1,465 of these were from one sample. Details of samples are given in Appendix D. There were also a few samples of anchovies from the stomachs of larger fish, which were on that account too much digested for precise measurement. All these samples were obtained from the waters of the east coast and Furneaux Islands, but there are reliable reports which leave no doubt as to the presence of the species on most parts of the Tasmanian coast.

The measurement data are insufficient for any work on analysis of length frequency distributions. However the following is a summary of the available records in respect of locality, season, and size.

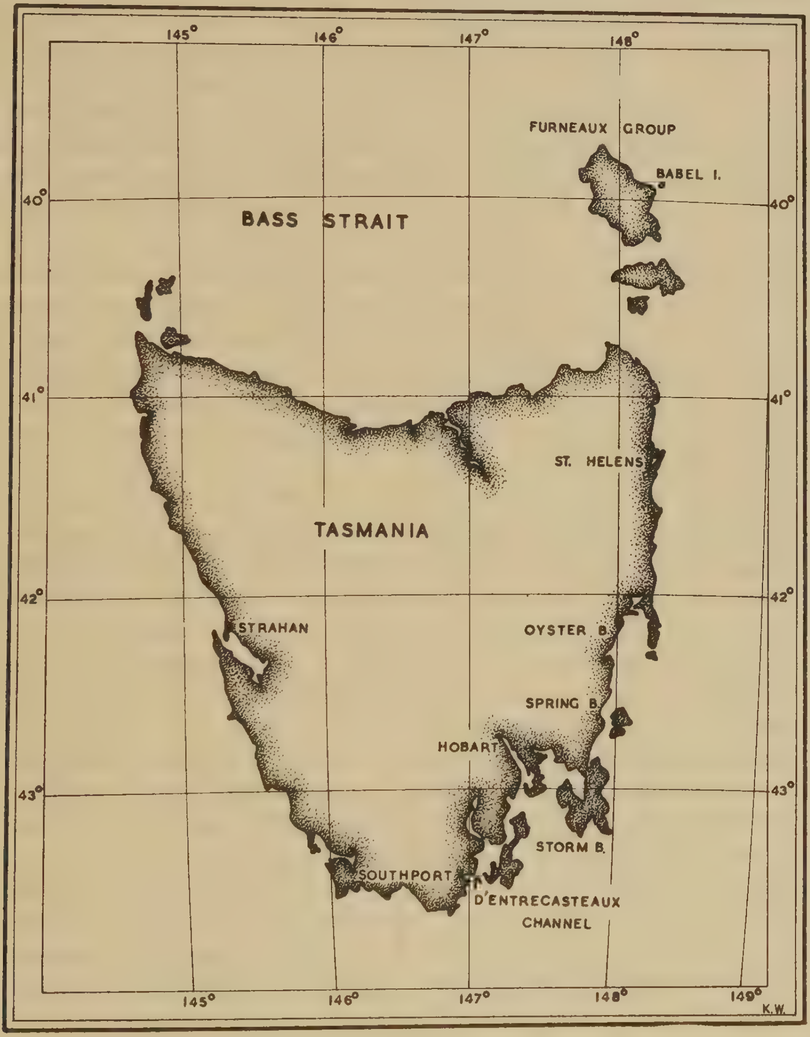
145°
146°
147°
148°
149°
40°
41°
42°
43°
FURNEAUX GROUP
BABEL I.
BASS STRAIT
TASMANIA
ST. HELENS
STRAHAN
OYSTER B.
SPRING B.
HOBART
STORM B.
SOUTHPORT
D'ENTRECASTEAUX CHANNEL
K.W.

Fig. 5.—Tasmania, showing localities mentioned in text.

Furneaux Group.—Several small samples were obtained, mostly from the stomachs of southern bluefin tuna. Nearly all were taken in open sea waters, but often within a few miles of land. Most of them were obtained from March to August (in various years), and the fish ranged from postlarval sizes to 104 mm.

George's Bay (*St. Helens*).—This is a well-enclosed inlet on the north part of the east coast. Specimens measuring from 62 to 95 mm. were taken on several occasions between December 1941 and February 1942. Most of the fish were obviously of the one age which, from the scale-readings, was 2 years. The evidence of several reports and of one or two specimens taken in other years, suggests that these are the usual sizes of fish present in this inlet in the summer. They are seen in the shallows in the late spring and disappear at the end of summer. The anchovies sometimes seen in the winter months in the shallow waters are usually smaller. One observer who saw specimens captured in July stated that they were from 2 to 2½ in. in total length, which indicates that they were of the O-group.

Central east coast.—Postlarvals were found in Spring Bay in January, a few fish from 51 to 64 mm. were obtained from bluefin tuna stomachs in May, and a good catch of larger fish was made in June in Oyster Bay, a broad gulf well open to the sea. The latter ranged in size from 57 to 97 mm. and were mainly of one age-group; few had any scales when studied, but judging from the Victorian length frequency studies, the fish were mainly about 2½ years old.

Storm Bay area.—A few O-group anchovies were taken at Port Arthur in June, and other fish from 77 to 103 mm. in Norfolk Bay in April. These are both well-enclosed waters. Still larger ones (108 to 126 mm.) were found in barracouta stomachs in Storm Bay in December.

D'Entrecasteaux Channel.—Lampara hauls of sprats (*Clupea bassensis*) made in the southern part of the Channel from March to August have generally yielded a few anchovies mixed with the sprats. Generally they accounted for less than 1 per cent. of all the fish taken, but in one haul the proportion was 10 per cent. These fish were always large, the specimens measured ranging from 83 to 136 mm. The specimen at 136 mm. (equivalent to 158 mm., or 6.2 in., total length) was the largest anchovy recorded from any Australian locality.

Southport.—O-group fish were taken in this inlet in April. In December several fish were captured which ranged in length from 68 to 116 mm., but mostly concentrated in one age-group with modal size 72 mm., i.e., probably 2 years of age. According to local observers, fish of these sizes are abundant in the late spring and summer only, as at St. Helens.

Observations on gonad maturity stages were naturally not as numerous as those made upon Victorian fish. However, the spawning period is much the same as in Victoria, i.e. broadly in the summer. The only months in which definite stage 5 individuals were noted were December and January. Some spent and spent recovering fish also occurred from January to April. There was confirmatory evidence from plankton hauls, which is dealt with below. The question of length at first maturity cannot be settled for Tasmania, although it could be the same as for Victorian anchovies. Of all the fish taken from December to February (there were none for

November) all the females were definitely at stage 2 or later. This was also true of most males, and those which were recorded as at stage 1 were nevertheless thought not to be immatures (cf. observations in Section III (*b*)). As the smallest of any of these fish was 62 mm., the length at which most individuals first mature is probably less.

The best evidence as to the time of spawning is provided by a series of plankton hauls made in the d'Entrecasteaux Channel. The writer examined 71 catches, which were made at approximately monthly intervals for the same six stations from January 1945 to February 1946, with the "Discovery" N70 net hauled for 15 minutes at the surface. Apart from one anchovy egg in one April haul, there were no stages of this species from March to September inclusive. The October hauls contained no more than one or two eggs each, but in November and January (there were no hauls in December) the numbers were highest, falling off in February. A few isolated hauls made in the same area in earlier years yielded similar results. The November-January hauls yielded very varying numbers of eggs, at most stations less than 100, but at one station (Simpson's Bay, which consistently yielded more than any other) one haul of about 5,000 eggs was obtained. This compares well with the best catch for Port Phillip Bay. Another excellent catch was from an isolated 15-minute tow with the N50 in the Southport inlet in December, when about 1,500 anchovy eggs were taken.

For Tasmania, it is possible to compare quantitative occurrences of planktonic anchovy stages in the more enclosed waters (i.e. those just discussed) with those at sea, which could not be done for Victoria.* The most striking evidence is that of catches by nets much larger than any of those used inshore, namely the "Discovery" N100 and N200. These nets capture larvae only, as the eggs apparently pass through the meshes. Some results have been published (Blackburn 1941, pp. 123-134), and these show that anchovy stages were very sparse in Tasmanian offshore waters. The largest capture consisted of 113 larvae off Babel Island in January, in a 30-minute haul with the N200, and has not been exceeded since those results were compiled. The next best haul contained only two larvae, and most (including all made outside the continental shelf boundary) were negative, even in the summer.

Tows have also been made with the N70 (often for 30 minutes, otherwise for 15), and these took some anchovy eggs, although larvae still predominated, which is the reverse of the usual results with the same gear in bay waters. This material has not been fully examined, but in the first two years of operations there were 29 hauls of this net at stations inside the continental shelf boundary ("shallow" stations) and 23 outside it ("deep" stations). Of the former, only 2 (both 30-minute hauls in January) yielded anchovy stages and then only a few in each case; of the latter, all were negative. The numbers of hauls actually made in the general spawning season (taking this from November to February inclusive) were 10 and 5 at shallow and deep stations respectively, so that the total anchovy material obtained at this optimum period was very small even in the shelf waters. From the evidence of both the N70 and the larger nets, the average towing time of which was longer than that in the d'Entrecasteaux Channel waters, it must be concluded that the amount of spawning at sea is much less than that in the more circumscribed inshore waters. It follows that in summer mature anchovies must be much more plentiful in the latter areas than out at sea, a conclusion which was reached for Victoria from other evidence.

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* See footnote at end of Section III (*b*).

There were not sufficient data to draw any very definite conclusions about the sex ratio. In the limited material available the sexes occurred in approximately equal numbers.

(*b*) *Age-studies with Scales*

The scales were collected and examined in the same way as for Victorian fish. They and their age-rings were similar in all respects to the Victorian material and were also comparable in legibility (see Plate 3, Figure 2 and Plate 4, Figure 1, which show Tasmanian scales).

There were 387 scales for which the scale dimensions (S) were recorded, taken from 148 fish. The means of L (fish-length) and S are presented, for half-cm. intervals of L, in Appendix E. The range of L for which data are available is less than that for Victorian material, commencing at 6.0 cm., and it was obvious that the relationship over this range was practically linear. The calculated regression equation is:

$$L = 37.5 + 21.5\,S$$

and the position is shown in Figure 6, where the L/S relationships for Tasmania and Victoria are compared. There is clearly a considerable difference, and intermediate lengths for Tasmanian fish cannot be calculated by direct proportions over any but perhaps the uppermost portion of the range. Not all the points on the Tasmanian regression line are based on adequate numbers of observations, but at least four of them are (see Appendix E). These are quite different from the corresponding Victorian data and the line of the above equation fits them reasonably well. Actually both the constants could be slightly different without affecting any of the intermediate length calculations at all. The difference between the regression coefficients for the Victorian and Tasmanian equations is highly significant. Since the position is so different in respect of the range of L from 6.0 cm. upwards, the relationship for lower values of L and S must also be somewhat different from that which applied for Victorian fish. If scales first appeared at the same average fish-length as in Victoria (i.e. 35 mm.), the relationship would actually be linear over the whole of the range, which is theoretically inadmissible (cf. Section III (*c*) (ii)).

This creates difficulties in calculating intermediate length (L_n) values from Tasmanian anchovy scales. In all instances where L_n values (calculated by direct proportions) are at or over 60 mm., they can be converted by the formula

$$L_n = L_n^1 + 37\ (1 - \frac{L_n^1}{L})$$

where L_n^1 is the value calculated by direct proportions (cf. Section III. (*c*) (ii)). It can be shown that this will also serve for converting L_n values down to about 40 mm.,* and, as this covers the range of L_2 readings (actually one is at 38 mm.), all values of L_2, L_3, etc., can be calculated. However, still lower L_n values converted on this basis would probably be too low, because of the presumably faster growth of the scale at scale-sizes below 1 mm. As most of the L_1 values calculated by direct proportion are below 40, reliable figures cannot be obtained for L_1.

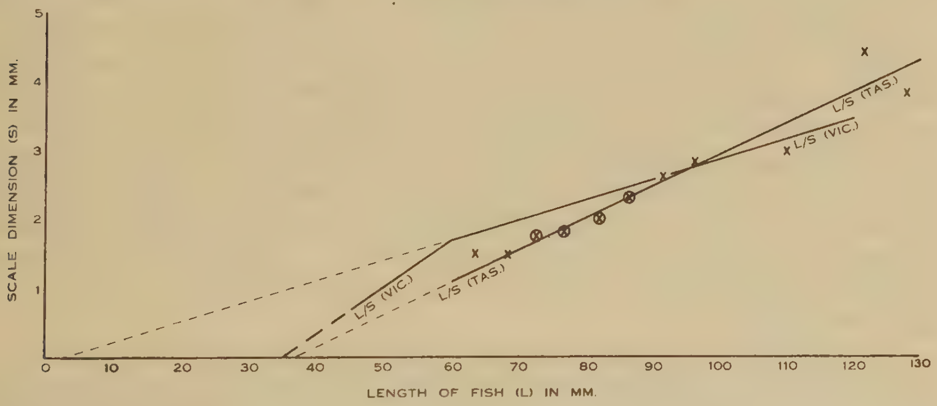

Fig. 6.—The fish-length/scale-length relationship for Tasmanian anchovies, compared with that for Victorian fish. The plotted points (X, and those based on large numbers of observations "X in circle") refer to Tasmanian data only.

Because of the limited material, it is impossible to deal very satisfactorily with the question of season of formation of the annual rings. Such evidence as there is corresponds more or less with that for Victorian scales, and there is little doubt that the position is much the same, and that the rings can be regarded as "winter rings." The great bulk of the available Tasmanian scales refer to fish of the 1939-40 year-class at

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* From about $L = 90$ mm. and upwards, L and S are nearly in direct proportion. Extrapolating to the origin, it is found that $L =$ about 40 when $S = 1$ mm. As 1 mm. is the minimum value of S in the relationship actually demonstrated, it follows that direct proportion-calculated L_n values down to about 40 mm. can be converted by the formula above.

St. Helens, sampled from December 1941 to June 1942. Some of these have two rings and a wide margin and others have a third ring at the edge, and it is the proportion of the latter at the different sampling periods that is of interest. Summarizing, and referring to only one scale from each fish, there are:

In December, 2 scales, none with ring at edge (0 per cent.).
In January, 66 scales, 53 with ring at edge (80 per cent.).
In February, 9 scales, 8 with ring at edge (89 per cent.).
In June, 18 scales, 17 with ring at edge (94 per cent.).

These results may be compared with those in Table 6, with which they agree quite well as far as they go. The proportion of scales bearing the ring in question (i.e., the third), is already high in January and then increases up to June. The situation is again shown more convincingly from the individual scale examinations, because most of the January scales counted as having the ring at edge have only the first signs of it, whereas in later months it is much better developed. It should be mentioned, however, that the February and June material from St. Helens consisted of samples withdrawn from a floating pen or cage in which some anchovies were placed in January, just before the main body of fish disappeared from the shallow waters. Thus the February fish had been in captivity for about three weeks and the June ones for about four months, and were not even in their normal water environment, when they were withdrawn and preserved. They were, however, fed regularly and adequately and were observed to take the food freely. Plate 4, Figure 1 shows a scale from a fish which survived four months' captivity, being removed in June at the end of the experiment.

In addition to the abovementioned 387 scales from 148 Tasmanian fish, there were 5 other scales from 3 fish whose age could be determined, although the scales could not be measured. Thus in all 392 scales were read from 151 fish. Table 14 shows the distribution of these individuals by size and age, the latter indicated by the number of rings (including those at the scale-margins), as was done for Victorian material in Table 7.

The data are limited, but they agree with those for Victoria, bearing in mind that most of the fish were taken at the period of formation of the third ring. The proportion of uncertain instances is somewhat higher at the lower sizes, because of the more restricted scope for comparisons between scales, which assist in recognizing secondary rings.

The range of adjusted values of L_2 and L_3 (there being no reliable estimates of L_1 and only one value of L_4) was as follows:

L_2 — from 57 to 80 (24 mm.)
L_3 — from 66 to 90 (25 mm.)

The range is in each case more restricted than that of Victorian values, presumably because of the smaller material, but it is clear that the means must be of a similar order (cf. Section III (*c*) (vi)). In investigating the matter further, it is convenient to ignore the few scales from fish other than those taken at St. Helens from December 1941 to June 1942. Material of two year-classes, namely 1939-40 and 1938-39, is available, but mostly belongs to the former. Table 15 shows the means of L_2 and L_3 for fish of these two broods, separately by sexes.

TABLE 14

NUMBER OF TASMANIAN ANCHOVIES WITH DIFFERENT NUMBERS OF ANNUAL SCALE-RINGS, FOR SUCCESSIVE HALF-CM. OF FISH-LENGTH

Length-group (cm.)	1 Ring	2 Rings	3 Rings	4 Rings	Uncertain	Total
6.0	—	2	1	—	—	3
6.5	—	1	1	—	—	2
7.0	—	8	7	—	4	19
7.5	1	6	40	2	2	51
8.0	—	5	28	8	3	44
8.5	—	4	10	2	4	20
9.0	—	1	1	1	1	4
9.5	—	—	1	—	3	4
10.0	—	—	—	—	—	—
10.5	—	—	—	—	—	—
11.0	—	—	—	—	1	1
11.5	—	—	—	—	—	—
12.0	—	—	—	—	2	2
12.5	—	—	—	—	1	1
					Total	151

TABLE 15

MEAN CALCULATED INTERMEDIATE LENGTHS (L_2, L_3) FOR ANCHOVIES OF TWO YEAR-CLASSES TAKEN AT ST. HELENS FROM DECEMBER 1941, TO JUNE 1942, WITH MEAN FISH-LENGTHS (L) IN RESPECT OF CORRESPONDING SCALES, SEPARATELY BY SEXES

Age in Years, and Year-class	Sex	L_2			L_3		
		Mean L_2	Mean L	n*	Mean L_3	Mean L	n*
2-2½ 1939/40	Female Male	66.92 65.57	81.26 76.72	39 54	— —	— —	— —
3-3½ 1938/39	Female Male	63.86 62.86	83.00 79.64	7 14	74.33 73.00	82.83 79.58	6 12

* n indicates number of observations; other units in mm.

These results suggest that the females grow very slightly faster than the males. The difference between the L_n means for the sexes is only 1 mm. for each of the three pairs, although that between the L means is 3 to 4 mm. These are the only data that provide any very satisfactory evidence on this point for anchovies anywhere in Australia, but the situation is possibly the same elsewhere.

The L_2 means are lower in the older of the two age-groups, as was also found for Victorian fish, although it is theoretically possible in this instance that the difference was associated with year-class instead. Since the L_2 and L_3 means would very probably be lower, and more reliable, in material of still older groups of fish (see Section III. (*c*) (vi)), any comparison of growth rate with that of Victorian fish can be made only with the data relating to similar ages. That is, the 1939-40 St. Helens fish, some of which have 2 and most of which have 3 rings on the scales, must be compared with the 2- and 3-group material in Table 11, and the 1938-39 fish with the 3- and 4-group material. The comparison shows that the growth rate of anchovies at St. Helens is slightly less than at Gippsland Lakes, but approximately the same as at Port Phillip Bay. However, if the L_n values had been calculated on the assumption that the L/S relationship was the same as for Victoria, they would have indicated a considerably inferior growth rate for Tasmanian fish. If the direct-proportion relationship had been assumed for both regions without any investigation, the result would have been similar. Both kinds of assumption have often been made, and must invalidate some of the conclusions on growth rates that appear in the literature.

(*c*) *Remarks on Life History*

The results of the biological study of the Tasmanian anchovies are too disconnected to yield any general picture of the life history. However, it is probably much the same as in Victorian waters, as stated in Section III. (*e*). Practically all the separate pieces of evidence are in line with those established for Victoria, as shown by the following summary:

(1) Spawning takes place in the late spring and summer, and on a much larger scale in the circumscribed inshore waters than in the open sea. The length at first maturity is not known precisely, but could be the same as in Victoria.

(2) The growth rate is practically the same as in Victoria.

(3) Yearlings probably have a special habitat in the inshore waters, distinct from that of the older fish. This is deduced from the fact that individuals of the appropriate size (about 50 to 65 mm.) are not conspicuous at sea (although both younger and older fish have been found there) and have not been found at all in the estuarine waters where the two-year-olds and larger fish were common. This is very reminiscent of the situation at Port Phillip, where the yearlings are concentrated in one particular part of the bay and older fish occur elsewhere.

(4) Anchovies aged 2 years and over are plentiful in certain inlet waters (e.g. St. Helens, Southport) in the summer, but soon disappear. At $2\frac{1}{2}$ years and over, i.e. in the succeeding winters, they are found in more open waters (e.g. Oyster Bay, south d'Entrecasteaux Channel, and open seas off the Furneaux Group).

This is generally similar to the situation at Gippsland Lakes and elsewhere. There are also reports from fishermen that medium-sized and large anchovies shoal at sea off the Tasmanian north coast from July to September, but the author has not seen any specimens.

V. THE ANCHOVY IN NEW SOUTH WALES AND QUEENSLAND

(*a*) *Distribution, Length, and Maturity*

There is virtually no commercial fishery in these States, but small quantities are occasionally sold in the Sydney fish market and seaside fish shops. Apart from a few such samples, the specimens studied were obtained by special sampling for research purposes. Details of samples are given in Appendix F. The total of measured fish is 8,954, but the data are not useful for length frequency studies. Over half the fish were from one sample and nearly a thousand others were postlarvals. The following is a summary of the available records (including a few of digested unmeasurable specimens from the stomachs of larger fish) in respect of area, season, and size.

New South Wales south coast.—This is the region south of Port Jackson (Sydney). Nearly all the specimens were taken from August to February. Some were from the open sea (continental shelf waters), some from the larger bays (Twofold, Jervis) and some from a much more enclosed water, the Wagonga Inlet. The Wagonga anchovies ranged from 55 to 94 mm. In the bays and open sea fish of all sizes were encountered, from postlarvals up to 131 mm. (the largest recorded anchovy for New South Wales), but most of the postlarvals were found in the bays and so were most of those at the largest sizes (over 90 mm.). The postlarvals were found from early October onwards.

New South Wales central coast.—There are significant data from Port Jackson and Lake Macquarie. Samples have been taken from May to September, the range of size being from 49 to 94 mm.

New South Wales north coast.—A few specimens ranging from 43 to 85 mm. have been procured from the Richmond River entrance (Ballina) in various months from February to July. They were noted in samples of sandy sprats sold locally for bait, but similar samples obtained in other months of the year did not contain anchovies. Postlarvals were found at the Nambucca River in January.

Queensland south coast.—Only 73 specimens have been obtained, 50 of them from off Coolangatta beach in April. The latter measured from 53 to 71 mm. Of the rest, some were postlarvals taken in the Noosa River in May, and others, from postlarval sizes up to 55 mm., were obtained in Hervey Bay in July. As noted earlier, the Capricorn Islands constitute the most northerly positive record for the species. Anchovies at maturity stage 5 were taken at Twofold Bay in November

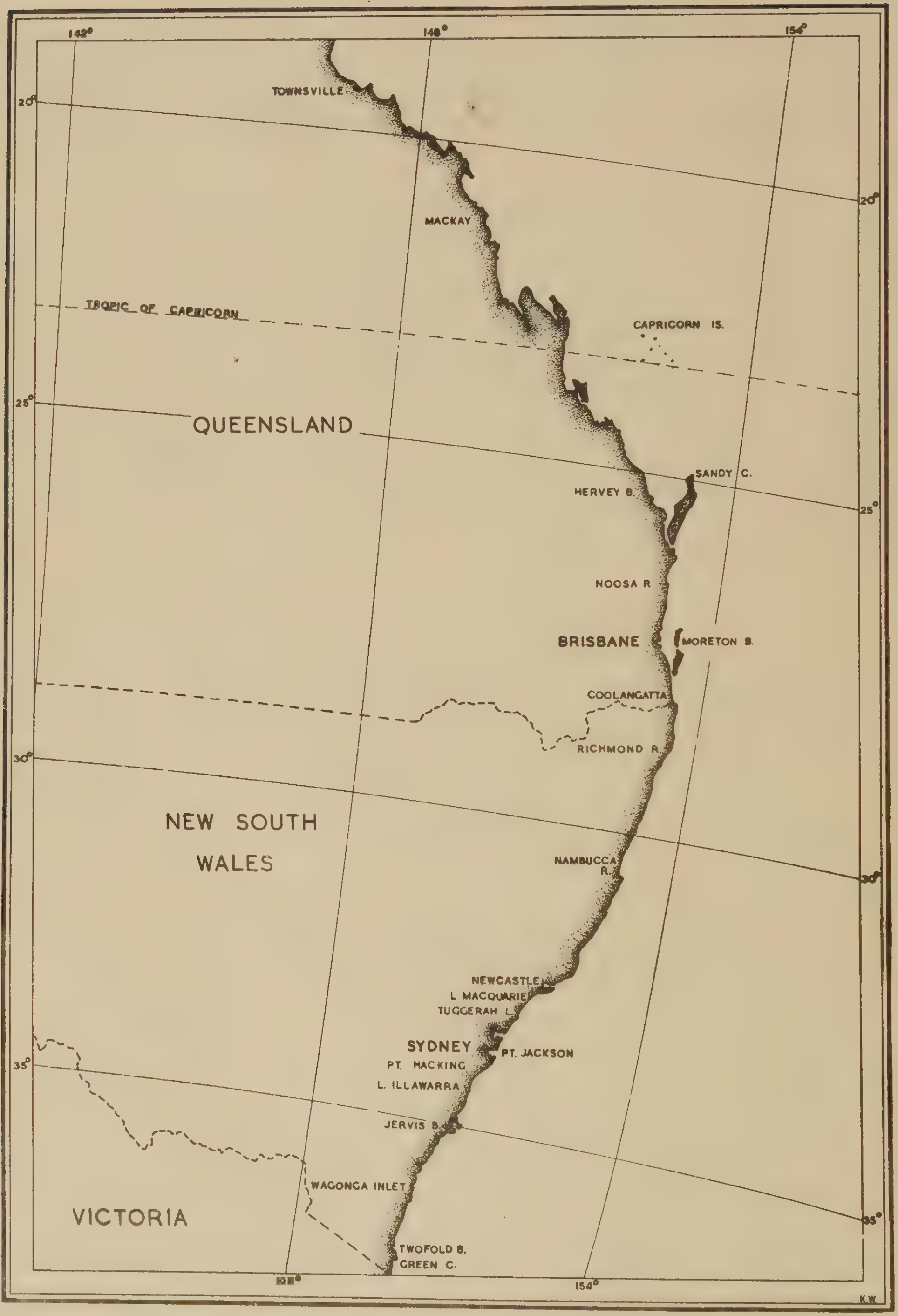
142°
148°
154°
TOWNSVILLE
20°
20°
MACKAY
TROPIC OF CAPRICORN
CAPRICORN IS.
25°
QUEENSLAND
SANDY C.
HERVEY B.
25°
NOOSA R.
BRISBANE
MORETON B.
COOLANGATTA
RICHMOND R.
30°
NEW SOUTH WALES
NAMBUCCA R.
30°
NEWCASTLE
L. MACQUARIE
TUGGERAH L.
SYDNEY
PT. JACKSON
35°
PT. HACKING
L. ILLAWARRA
JERVIS B.
WAGONGA INLET
VICTORIA
35°
TWOFOLD B.
GREEN C.
154°
K.W.

Fig. 7.—New South Wales and Queensland, showing localities mentioned in text.

and January; at Wagonga Inlet in August, October, and November; at Lake Illawarra in January; and at Port Jackson (in fair numbers) in June, July, and August. Because samples are not available for many of the other months from these localities, the foregoing observations do not necessarily indicate the full range of the spawning seasons; but it is obvious that, whereas the season at Twofold Bay could be the same as in Victoria and Tasmania, it possibly starts somewhat earlier at Wagonga Inlet, and definitely much earlier at Port Jackson.

The distribution of larvae in the plankton of the shelf (neritic) waters, as sampled by the larger plankton nets, has already been investigated (Blackburn 1941, pp. 84, 85). It was concluded that on the New South Wales south coast (including the waters off Port Jackson), the peak spawning season was the summer, although larvae were also found in spring and autumn. In northernmost New South Wales and in south Queensland waters there were occurrences in the spring on much the same scale as those in summer on the south coast, and there were also several records of larvae in the winter. It was therefore suggested that the optimum spawning season might be the spring, although the area had not been examined in summer. It has not been possible to make this examination since, and in fact none of the results of more recent plankton work in New South Wales or Queensland coastal waters added anything important to our knowledge of this matter. The anchovy stages from the N70 plankton catches (which included some eggs as well as larvae) had a similar distribution. Dakin and Colefax (1933, pp. 212-213; 1940, p. 203) found that these stages were most abundant off Port Jackson from November to January.

Plankton collecting in the bay and inlet waters of this part of Australia has been confined to Port Hacking, just south of Port Jackson, and several waters on the New South Wales central and north coasts and in Queensland. The author examined 69 catches, made at regular intervals in Port Hacking, from September 1941 to August 1942, with a 50 cm. diameter net towed for 10 minutes at the surface. The only months in which any anchovy stages (eggs) were taken were September, October, November, December, and April, and the numbers were extremely small, the maximum for any haul being 9 and the total for the 12 months only 22. The other hauls, 268 in all, were made with similar gear by Mr. I. S. R. Munro, who kindly checked all the collections for anchovy eggs. Such eggs were found in only two catches, one from Tuggerah Lakes in August (about 20 individuals) and one from Bribie Passage in June (1 or 2 individuals). Not all the waters were examined at all times of the year, but this was done for Bribie Passage (Moreton Bay) and Noosa River (both in Queensland), where there were 40 and 153 hauls made respectively, in various years.

It therefore seems from all the evidence that the peak spawning season is the summer on the New South Wales south coast, as it is in

Victoria and Tasmania. The same is probably true of Port Jackson and the neighbouring waters, but some spawning takes place as early as the winter. Further north, particularly in northern New South Wales and in Queensland, the position is not quite clear, but there is certainly a significant amount of spawning in the winter and spring. If the optimum season does not become progressively earlier to the north, there is at least a tendency for significant spawning to begin earlier at lower latitudes. It was noted above that postlarvals have been found as early as October even in south coast waters.

The same data indicate the surprisingly small amount of spawning that occurs in the inlet waters from central New South Wales northwards. At Port Hacking the maximum number of stages (eggs) in one haul was 9, and elsewhere (Tuggerah Lakes, just north of Port Jackson) it was about 20, the net in both cases being of 50 cm. diameter and hauled for 10 minutes. This may be compared with a catch of 112 eggs reported by Dakin and Colefax (1933, p. 212) from off Port Jackson in January 1931, which was made with a net of only 35 cm. diameter, towed for 10 minutes. Catches of up to 85 larvae have been made in the shelf waters (Blackburn, loc. cit., Table 1), but with much larger nets towed for longer periods. In Queensland waters only 1 or 2 eggs have been taken altogether for a large number of inlet hauls at all seasons, but out to sea individual catches of up to 27 eggs have been taken with the N70 net towed for 30 minutes (in September). The situation is therefore not the same as in Victoria and Tasmania, where the greatest concentrations of eggs and larvae occur in the enclosed waters. There is no evidence for south of Port Hacking, but for the rest of the eastern seaboard it is clear that spawning takes place mainly at sea, whatever the season may be. However, larvae are rarely found outside the edge of the continental shelf.

The available data are insufficient for determining length at first maturity.

Samples taken on the south coast in November and January nearly all had a large preponderance of females, whereas samples from other areas in winter (Port Jackson, Lake Macquarie, Coolangatta) had the sexes in approximately equal proportions.

(*b*) *Age-studies with Scales*

There were 333 scales available for examination, taken from 105 fish. Virtually only two widely separated districts were represented in this material, viz. Port Jackson — Lake Macquarie in central New South Wales (47 fish), and Coolangatta in Queensland (44).. Apart from the possibility that the L/S relationship might be different in these areas, the total material is insufficient for such a study. However, the New South Wales scales were larger than the Victorian ones, which, as already shown, were larger than those from Tasmania, for fish of comparable size. On the other hand the Queensland scales, from younger fish, were similar in size to those from comparable individuals from Victoria. Thus for at least part of the range of size, there is a progressive change in the form of the L/S relationship from south to north, and that for New South Wales is certainly more like that for Victoria than that for Tasmania. Table 16 shows the available data on means of S (excluding those based on less than 20 observations) for fish of the different States, at the same half-cm. intervals of fish-length (L). The figures for Victoria and Tasmania are taken from Appendices A and E.

TABLE 16

MEANS OF SCALE-LENGTH (IN MM.) FOR FISH AT SUCCESSIVE HALF-CM. INTERVALS OF BODY LENGTH, FROM DIFFERENT STATES; ALL BASED ON 20 OR MORE OBSERVATIONS

State	Fish-length (half-cm.)						
	5.5	6.0	6.5	7.0	7.5	8.0	8.5
Queensland	1.52	1.71	—	—	—	—	—
New South Wales	—	—	2.33	2.41	2.68	3.21	3.43
Victoria	1.56	1.79	1.96	2.15	2.35	2.51	2.22
Tasmania	—	—	—	1.75	1.82	2.01	2.29

Another difficulty about precise studies with these scales was that the season of formation of the annual rings could not be established beyond doubt. The only months for which there were scales from more than 5 fish were April, with 44 (Coolangatta), and May, with 31 (mostly

TABLE 17

NUMBERS OF NEW SOUTH WALES AND QUEENSLAND ANCHOVIES WITH DIFFERENT NUMBERS OF ANNUAL SCALE-RINGS, FOR SUCCESSIVE HALF-CM. OF FISH-LENGTH

Length-group (cm.)	1 Ring	2 Rings	3 Rings	4 Rings	Uncertain	Total
5.0	1	1	—	—	—	2
5.5	12	10	1	—	2	25
6.0	5	6	4	—	3	18
6.5	5	2	5	—	3	15
7.0	—	6	1	—	2	9
7.5	—	6	2	—	1	9
8.0	2	2	4	—	1	9
8.5	—	4	3	—	2	9
9.0	—	—	1	1	—	2
9.5	—	—	1	1	2	4
10.0	—	—	—	—	1	1
10.5	—	—	—	—	—	—
11.0	—	—	—	—	—	—
11.5	—	—	—	—	—	—
12.0	—	—	—	—	2	2
					Total	105

central New South Wales). The numbers which had a ring at the edge were respectively 10 (23 per cent.) and 23 (74 per cent.). It is thus very probable, but not certain, that the rings are formed in winter, as in Victoria.

Practically all that could be done with these scales was, therefore, merely to record the number of rings for those of each fish. Table 17 shows the dissection of the material by size and age, the latter indicated by the ring-number (including rings at scale-margins), similarly to Tables 7 and 14.

As far as these data go they agree very well with those for Victoria and Tasmania. There can be no doubt that the growth rate is approximately the same throughout eastern Australian waters.

(c) *Remarks on Life History*

There is insufficient information from which to deduce the life history of the fish in these waters. However it is obviously different in many ways from that of the species in Victorian and (probably) Tasmanian waters, at least over most of the area, although the growth rate is apparently much the same. The differences are as follows:

(1) Although the general spawning season is much the same on the south coast as in Victoria and Tasmania, it tends to be earlier (either altogether, or perhaps merely starting earlier) from about Port Jackson northwards. Possibly this even operates on part of the south coast.

(2) At least from about Port Jackson northwards, spawning takes place on a larger scale in the open sea than in the inlets.

(3) There is a suggestion that anchovies are more plentiful in at least the more northern inlets (e.g. Port Jackson, Richmond River) in the autumn and winter than later in the year. This could obviously be connected with (1) and (2) above, implying a spring migration out to sea to spawn, in contrast to the reverse movement at the same season in Victoria.

VI. THE ANCHOVY IN SOUTH AUSTRALIA AND WESTERN AUSTRALIA

Information from these areas is meagre, for South Australia particularly so. Details of samples are given in Appendix G, and there were a few others, from the stomachs of larger fish, which were unmeasurable. Some anchovies were taken in the more open waters of South Australia from December to May, in the stomachs of southern bluefin tuna, barracouta, salmon, and tommy ruffs. Those measured ranged from postlarval sizes up to 89 mm. Other fish were netted in Coffin Bay in March and April, the range of length being 72 to 114 mm. (see Fig. 1 for South Australian localities). Other inshore localities from which anchovies have been reported include the Coorong, Port Lincoln, Cowell (where large quantities were reported in July 1941), Port River (near Adelaide), and Hardwicke

Bay. Spawning is probably at its height in the summer, because hauls with the large "Discovery" plankton nets took larvae at that period in Lacepede Bay, St. Vincent's Gulf, and Investigator Strait, in quantities similar to those obtained with the same nets at the optimum season in Tasmania and New South Wales. Actually the months in which these results were obtained (the only ones in which observations have been made) were December, February, and March. The best catch was one of 77 larvae with the N100 net towed at the surface for 30 minutes (see Blackburn 1941, p. 86 and Table 1). The only anchovy at stage 5 was one taken in March at Coffin Bay, but nearly all of those sampled in April at the same locality were either at stage 7 (spent) or stage 2, recovering. No scale samples are available from South Australian fish.

The data from Western Australia are slightly more extensive. Anchovies occur in several of the south coast inlets, including Oyster Harbour at King George's Sound, Wilson's Inlet, Nornalup Inlet, and Brooks' Inlet. Specimens have been taken from one or another of these places in the months of February, March, August, September, and November, the range of length being 59 to 96 mm., but larger fish are reported. At Wilson's Inlet the fish are said to be very abundant at times, and local fishermen say they could catch commercial quantities with beach seines if there was any demand for them. This inlet is usually closed to the sea for about the first six months of the year, opening under pressure of winter freshets. An interesting and reliable report (from Mr. J. Munro of the Western Australian fisheries inspectorial staff) concerns the occurrence of anchovies at the Pallinup estuary, on the more arid part of the coast east of King George's Sound. This is closed to the sea at times for an unbroken period of some years, when the water is apt to become much more saline than the sea. Bream, mullet, and leatherjackets have been found dying under these conditions, but anchovies were apparently healthy.* Bearing in mind the occurrences in nearly fresh waters in the Gippsland rivers, it must be concluded that the species is remarkably tolerant of salinity variations.

On the west coast, samples have been procured from the Leschenault Inlet at Bunbury (June and October) and the Swan River estuary (September, October, November, and April). The fish from the Swan were mainly smaller than those from any of the other inlets, being similar in length to the yearlings at Hobson's Bay. Reports from fishermen indicate that they occur in fair abundance.

All other records refer to the open sea waters further north, where specimens have been obtained from the stomachs of northern bluefin tuna and the large-scaled tunny. All these records have been from June to November, but the area has not been adequately surveyed at other seasons.

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* **According to Mr. A. D. Butcher, similar phenomena have been observed in Lake Tyers, eastern Victoria.**

The most southerly occurrence was off Shark Bay. The most northerly positive one was at Red Bluff, but other engraulids taken as far north as North-West Cape (above the Tropic) were tentatively identified in

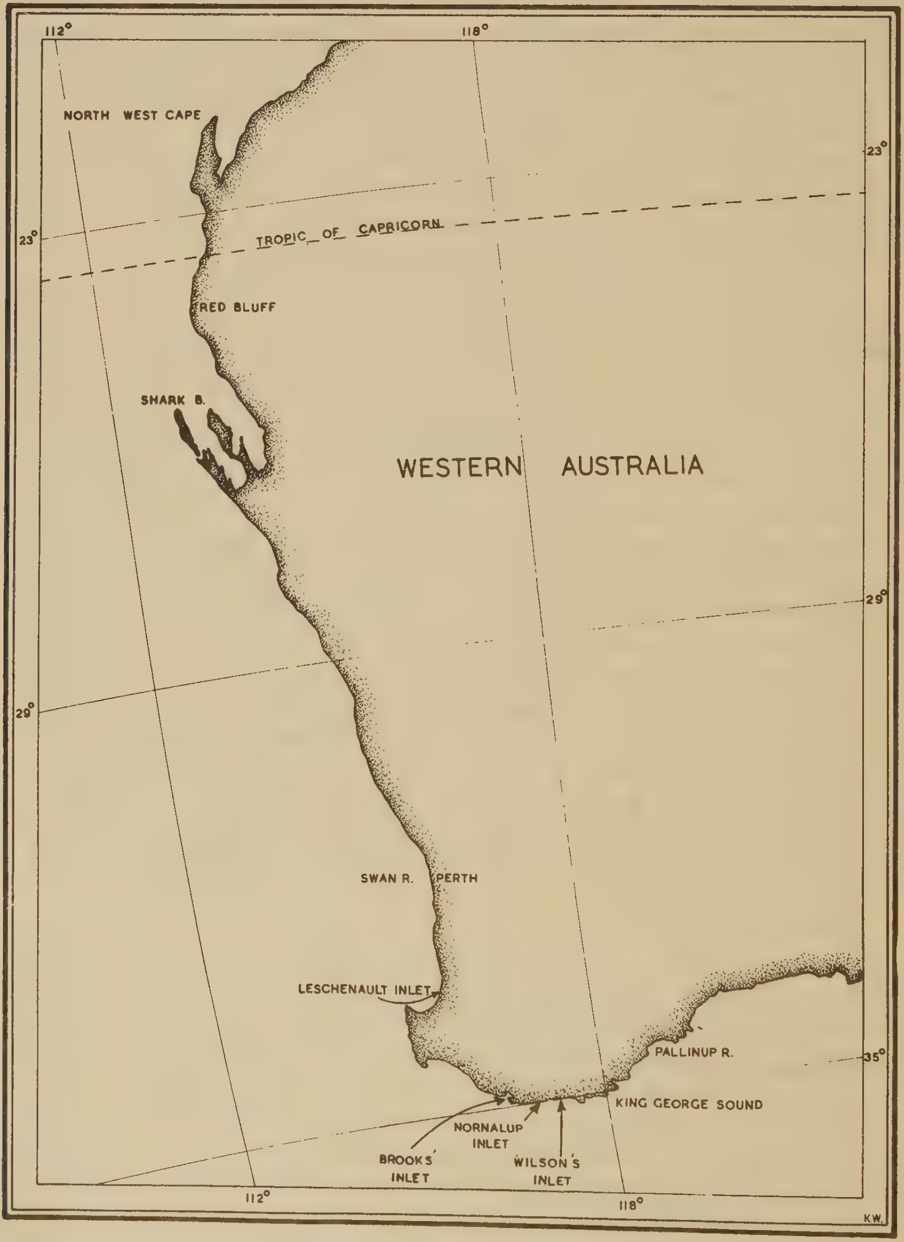
112°
118°
NORTH WEST CAPE
23°
23°
TROPIC OF CAPRICORN
RED BLUFF
SHARK B.
WESTERN AUSTRALIA
29°
29°
SWAN R.
PERTH
LESCHENAULT INLET
PALLINUP R.
35°
KING GEORGE SOUND
NORNALUP INLET
BROOKS' INLET
WILSON'S INLET
112°
118°
KW.

Fig. 8.—Western Australia, showing localities mentioned in text.

the field as this species, though afterwards lost. These specimens ranged in length from under 50 to 103 mm.

Very little has yet been done in the way of plankton collecting in this large area. The records of maturity stages are rather scanty, but fish at stage 5 have been found in November, March, April, and June, at various places from the Swan River to Wilson's Inlet. Stage 4 specimens have been obtained in September, October, November, February, March, and April. It is thus probable that the peak spawning season in the south-west is in summer, as in other parts of southern Australia. The data are insufficient for an investigation of length at first maturity, or sex ratio.

TABLE 18

NUMBERS OF WESTERN AUSTRALIAN ANCHOVIES WITH DIFFERENT NUMBERS OF ANNUAL SCALE-RINGS, FOR SUCCESSIVE HALF-CM. OF FISH-LENGTH

Length-group (cm.)	1 Ring	2 Rings	3 Rings	4 Rings	Uncertain	Total
4.5	1	—	—	—	—	1
5.0	1	—	—	—	—	1
5.5	10	—	—	—	—	10
6.0	4	1	—	—	—	5
6.5	1	3	—	—	4	8
7.0	1	4	1	—	2	8
7.5	1	10	4	—	3	18
8.0	—	—	2	—	—	2
8.5	—	—	2	—	—	2
9.0	—	—	2	—	—	2
9.5	—	—	—	1	—	1
					Total	58

179 scales were examined from 58 fish. This material was inadequate for a study of the *L/S* relationship, and thus there could be no precise study of intermediate fish-lengths. Furthermore it was not even clear at what season of the year the annual rings are formed, although this could be the same as in eastern Australia, as far as the scanty indications go. All that could be done was merely to record the age of each fish, as indicated by the number of rings on its scales. The results of this study are given in Table 18. A comparison with Tables 7, 14, and 17 reveals a satisfactory agreement. The general growth rate of the anchovy is probably similar, at least broadly, in western and eastern Australia.

VII. SUBSPECIES AND POPULATIONS

The foregoing studies have already provided several indications of some degree of heterogeneity of population in the large area over which the anchovy occurs. There are certain differences in spawning time and place, growth rate, scale size, and sex ratio. However, these do not give a very clear picture of the extent of the subdivision of the species into populations over the whole range, and it is desirable to investigate the matter further. In clupeoid fish, this is usually best done (apart from tagging where applicable) by a study of variation in number of vertebrae, and many vertebral counts were made in the course of these anchovy investigations. The records here are of the total number of vertebrae, including the urostyle, and all counts were made by the writer. Abnormal vertebrae were dealt with by counting the centra only.

Table 19 shows the frequency of occurrence of skeletons with different vertebral counts, for each locality from which 50 or more specimens were available. The number of observations (n), mean vertebra number (A.M.), standard deviation (S.D.), and standard error of the mean (S.E.) are also given. The total number of counts is 5,804.

TABLE 19

RAW DATA AND STATISTICS OF ANCHOVY VERTEBRAL COUNTS

Locality	Vertebrae									n	A.M.	S.D.	S.E.
	40	41	42	43	44	45	46	47	48				
Coolangatta (Q.)	—	—	7	31	12	—	—	—	—	50	43.10	0.614	0.087
Richmond R. (N.S.W.)	1	1	4	30	22	—	—	—	—	58	43.22	0.796	0.104
Nambucca R. (N.S.W.)	—	—	1	30	18	1	—	—	—	50	43.38	0.568	0.080
L. Macquarie (N.S.W.)	—	—	1	43	52	4	—	—	—	100	43.59	0.588	0.059
Pt. Jackson (N.S.W.)	—	—	4	38	135	25	3	—	—	205	43.93	0.664	0.046
Jervis Bay (N.S.W.	—	—	2	31	18	11	4	—	—	66	43.76	0.978	0.120
Wagonga R. (N.S.W.)	—	—	2	25	53	26	1	—	—	107	43.99	0.771	0.075
Twofold B. (N.S.W.)	—	—	1	9	37	127	68	11	—	253	45.13	0.868	0.055
Green C. (N.S.W.).	—	—	—	2	3	27	35	5	—	72	45.53	0.804	0.095
Gippsland Lakes Entrance (Vic.)	—	—	1	7	80	155	124	24	1	392	45.20	0.919	0.047
Gippsland Lakes Rivers (Vic.)	—	1	4	15	90	117	19	4	—	250	44.56	0.872	0.055
Westernport (Vic.)	—	—	—	—	6	104	77	13	—	200	45.48	0.665	0.047
Pt. Phillip B. (Vic.)	—	—	—	13	262	1802	1054	69	3	3203	45.29	0.664	0.010
Babel I. (Tas.)	—	—	—	1	7	25	22	12	—	67	45.55	0.958	0.117
St. Helens (Tas.)	—	—	—	—	1	62	117	30	—	210	45.84	0.658	0.046
Oyster B. (Tas.)	—	—	—	—	2	48	48	2	—	100	45.50	0.577	0.058
d'Entrecasteaux Channel (Tas.)	—	—	—	—	12	49	44	4	—	109	45.37	0.728	0.070
Southport (Tas.)	—	—	—	—	8	45	42	6	1	102	45.48	0.767	0.076
Coffin B. (S.A.)	—	—	—	—	3	53	43	5	—	104	45.48	0.638	0.062
Wilson's Inlet (W.A.)	—	—	1	23	55	6	2	—	—	87	43.83	0.668	0.071
Swan R. (W.A.)	—	2	8	39	20	—	—	—	—	69	43.12	0.718	0.087

Hubbs and Perlmutter (1942) described a method for the graphical summarizing of data of this type, and for detection of significance of differences between means by inspection of the graph. Figure 9 gives the information of Table 19 in this way. The significance of differences between means is appraised by comparing the relative length, and relative separation or overlap, of the corresponding rectangles, this process yielding *t* values.

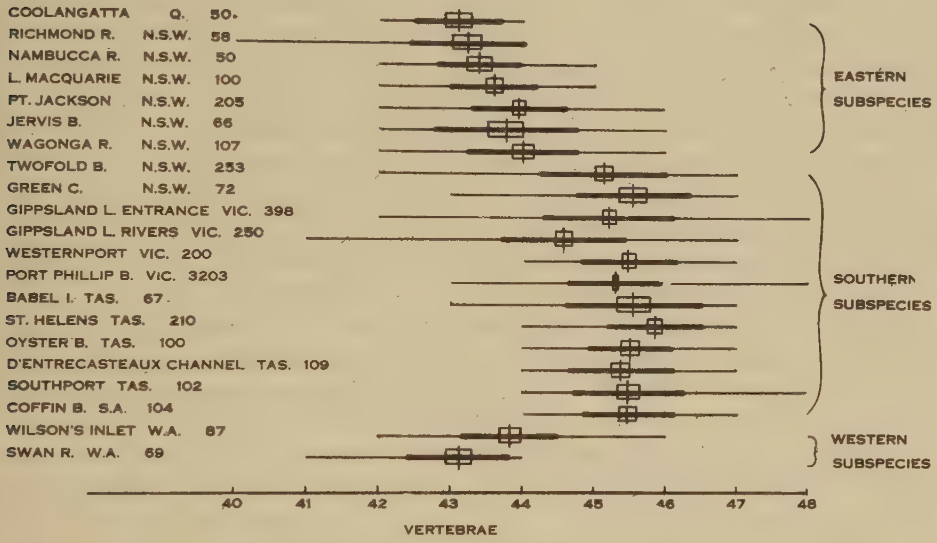

Fig. 9.—Summary of data on anchovy vertebral counts. The horizontal line in each instance indicates the range, the vertical cross-bar the mean, the thickened portion of the line one standard deviation on each side of the mean, and the hollow rectangle twice the standard error of the mean on each side of the mean.

In this case there are minor variations between means, for the appraisal of which the above method is appropriate. This is discussed below. However there is also variation of a much more notable kind, the significance of which is sufficiently obvious if only the means and standard deviations are considered. Leaving aside one locality (Gippsland Lakes rivers) which is a special case, the rest of the material falls very clearly into three groups. The anchovies of Queensland and New South Wales, north of Twofold Bay, have a range of vertebral number from 40 to 46, and the means of samples of 50 or more fish range from 43.10 to 43.99. Those of southernmost New South Wales (Twofold Bay and Green Cape), Victoria, Tasmania, and South Australia (Coffin Bay) have the range from 42 to 48, and that of the means from 45.13* to 45.84. The Western Australian fish have vertebral counts ranging from 41 to 46 and the means for the two available samples are 43.12 and 43.83. The difference of about

* Actually the range is from 44.90, as one sample of 50 from Twofold Bay had this mean; one sample of 100 from Lakes Entrance had mean 44.95.

one vertebra in the mean count in southern New South Wales, in the 60 or 70 miles separating Wagonga Inlet and Twofold Bay, is most remarkable.

Broadly speaking, the thickened bars representing the standard deviations neither greatly overlap nor are very much separated, as between the first and second (eastern and southern) of the three groups above, and the same applies for the second and third (southern and western) groups.* Hubbs and Perlmutter point out, following Ginsburg (1938, p. 260): "Such differences are approximately of the order that may be used for subspecific separation." These three groups of anchovies also fulfil the requirements of the more empirical definitions of subspecies, such as those of Huxley (1939, p. 105) and Mayr (1942, p. 106). The species was originally described by White from the Port Jackson district, and thus the eastern subspecies should be called *Engraulis australis australis* (White). For the southern form the name *antipodum* Gunther is available from the synonymy of the species, so that this becomes *E. a. antipodum.* The western subspecies requires a name, and is here designated *E. a. fraseri,* after Mr. A. J. Fraser (Chief Inspector of Fisheries in Western Australia, who made available some of the material). The zone of separation or intergradation of the two last is not known, but is probably in the Great Australian Bight, where there are hundreds of miles of unindented coastline.

Within each of these subspecies it is evident that subsidiary populations occur. This is particularly well shown for the eastern one, where there is a fairly regular tendency for the mean vertebra number to increase towards the south. This is an "internal cline" (Huxley loc. cit.). The position is very probably the same in the western sub-species, but is less obvious in the southern one. The graphical *t* test method of Hubbs and Perlmutter shows that there are at least three distinct populations of the eastern form, each one overlapping those adjacent. For instance, the means of the Coolangatta and Port Jackson fish are significantly different, and so are those of the Port Jackson and Wagonga River specimens, but each of these three means can be shown to be not significantly different from material of more adjacent places. In view of the possibility of vertebral variation by year-class as well as by locality (which is very probably the explanation of the slight irregularity in the cline), it is not easy to say for certain how many populations are present, or what is the geographical extent of each. However, from the data available there are probably three, statistically distinct, on the New South Wales coast.

In the western subspecies. it is obvious that the two samples, from

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*An analysis of variance was carried out to compare variation in vertebrae number between groups and within groups. It was found that the mean of the southern group was significantly higher than that of the eastern group, at the 1 per cent. level.

Wilson's Inlet and Swan River, are representative of two different populations.

The situation is less clear in the southern subspecies material. First of all it is necessary to comment upon the material from the Gippsland Lakes rivers, i.e. the Mitchell, Nicholson, and Tambo, which flow into the upper reaches of the Lakes. As mentioned previously (Section III (*a*)) salinities are very low in these rivers, even in summer. Hubbs (1925) found that two different populations of *Engraulis mordax* occurred in San Francisco Bay, one near the entrance and thence seawards, and the other "in the brackish waters." They differed in several ways, but most notably in mean vertebra number, which was two less in the latter form. Because it seemed difficult to reconcile the presence of large anchovies in the Gippsland Lakes headwaters with the fact that the individuals occurring in the upper part of Port Phillip Bay were mainly small, the possibility that there might be two populations in the Gippsland Lakes system, similar to those in San Francisco Bay, was considered.

It was easy to put the matter to the test because all the Gippsland Lakes samples were obtained either from the rivers or from the Entrance and adjacent sea, i.e. there was no material from the Lakes proper, where overlapping might take place. Figure 9 shows the result, The river fish have a mean which is two-thirds of a vertebra less than that of the entrance individuals, and this difference is, of course, highly significant, although probably not sufficient for the former group to be given subspecific rank. There are no data available for comparison of material of the same year-class from these two areas, but the following summary of means of separate samples shows that the highest mean for the river fish is well below the lowest for the entrance specimens:

Rivers

5.iv.44 (Nicholson): 44 fish: mean 44.23.
23.xi.44 (Nicholson): 93 fish: mean 44.66.
4.xii.44 (Tambo): 100 fish: mean 44.60.

Entrance

12.ix.44: 69 fish: mean 45.13.
8.xii.44: 100 fish: mean 45.00.
20.i.45: 100 fish: mean 44.95.
20.x.45: 100 fish: mean 45.51.

The anchovies of these rivers therefore constitute a separate population from those found at Lakes Entrance, and the situation is similar to that found by Hubbs in San Francisco Bay. All other references in this paper to samples of anchovies from "rivers" indicate captures in the lower reaches of the estuaries, and not in waters of low salinity comparable with those just discussed.

The rest of the data on the southern subspecies are still difficult to interpret. Applying the graphical t test, many of the locality-sample means are found to be not significantly different from others; these include some from very widely-separated areas, e.g. Green Cape, Southport, and Coffin Bay, the material from which cannot be separated on this basis. On the other hand the St. Helens mean is significantly different from all the others; but the means for Twofold Bay and Lakes Entrance are not significantly different nor are those for Lakes Entrance and Port Phillip, although there is a significant difference between the Twofold Bay and Port Phillip means. This does not yield an intelligible picture of the disposition of populations of the subspecies, although it is fairly obvious (and is shown more clearly below) that such exist. Considering that the locality-samples were mostly larger than those from the eastern and western areas, the irregularity in the series is rather surprising. The following are the possible explanations:

(1) There might be a significant difference in vertebral count between the sexes, which, in view of the observed variations in sex ratio between localities, could account for the irregularity in the locality-series.

(2) There might be a considerable interchange of individuals between populations.

(3) There might be considerable variation in mean vertebra number between fish of different year-classes in any population, and possibly also some apparent variation (due to selection) between age-groups of a year-class.

As regards (1) above, Table 20 shows that there is no such difference between the vertebral counts of males and females. As regards (2), the life history shows such an intermingling to be possible, and it can safely be said that it occurs to some degree, as it obviously does between populations of the eastern subspecies. The comparison with the latter serves to point out that such intergrading should still not occasion the sort of irregularity that is found with the southern fish. Furthermore there is probably more exchange between localities in eastern than in southern Australian waters, because over at least much of the former area the greater part of the spawning takes place at sea. Thus the very young stages could enter inlets other than those from which their parents came in addition to the transfers the older fish themselves might make, whereas

TABLE 20

MEAN VERTEBRA NUMBERS FOR MALES AND FEMALES IN FOUR HOMOGENEOUS SAMPLES

Material	Male			Female			t
	n	A.M.	Sx^2*	n	A.M.	Sx^2*	
St. Helens, 1939-40 class, 2-2½ yrs.	56	45.91	24.554	40	45.90	21.600	0.07
Gippsland rivers, 1940-41 class, 4 yrs.	15	44.40	11.600	19	44.53	16.737	0.41
Pt. Melbourne, 1943-44 class, 0-group	14	45.14	7.714	21	45.18	11.273	0.15
Pt. Melbourne, 1944-45 class, 0-group	36	45.19	15.640	49	45.24	31.062	0.30

* Sx^2 signifies sum of squares of deviations from mean.

in the southern waters only the second type of intermingling could be important. One is left with (3) as the most likely explanation of the variation observed. It is well known that variations in vertebral count between broods can be very important, and that apparent variations between age-groups can occur in clupeoid species (e.g. see Tester 1937).

Several hundred fish on which vertebral counts were made were identifiable as to year-class and age-group (by scale readings or from being obvious postlarvals) but, because of the number of localities, broods, and ages represented, it was hard to find much material which illustrated variation by brood or age at the same locality. There is some evidence of variation between broods, but not based on sufficiently extensive numbers of observations to be worth presenting. However the point is made sufficiently from the means of different samples of the two populations of Gippsland Lakes anchovies shown above, which include fish of a variety of broods and ages. There is considerable variation here which, bearing the above observations in mind, can scarcely be accounted for in any other way. Similar examples could be given for other places. It remains to explain why such vertebra number fluctuations between broods should be so much more marked in the southern subspecies than in the eastern, as they apparently are. Since the former fish spawn mainly in the inlets, and since the environmental factors (e.g. temperature) which tend to control the number of vertebrae in the young fish would probably fluctuate more widely and more independently (between localities) in the inlets than in the open sea, the matter is not particularly surprising.

The question of what populations exist, and where, cannot be finally answered. In view of the apparent importance of variations in mean vertebra number between year-class, completely reliable tests of significance of mean differences between localities would require to be made for material of the same year-class (and preferably of the same age). Some data of this kind are available, based on reasonable numbers of observations, but the only comparisons possible are between the Gippsland rivers on the one hand and (*a*) St. Helens and (*b*) Port Phillip on the other. This yields no further information, as it is already obvious that the Gippsland rivers fish are distinct from those of any other region. It was considered that the Tasmanian anchovies should at least be distinct from those on the mainland, regardless of whether there might be more than one population in either area. It can be seen from Table 19 that the samples from Twofold Bay, Green Cape, Lakes Entrance, and Westernport total 917 fish, with mean 45.27 and Sx^2 675.549. The very large Port Phillip sample (whose mean was, however, almost the same) was excluded, and so was that for Coffin Bay, as being geographically remote from the other localities. The total of Tasmanian fish was 588, with mean 45.60 and Sx^2 321.280. The value of t is 8.25 and hence the difference between the means is highly significant. These two samples are of comparable size.

which is large enough to discount effects of variation associated with broods.

It can safely be concluded that the fish of southernmost New South Wales and Victoria on the one hand, and Tasmania on the other, are either two distinct populations or groups of populations. For the rest, there is for the mainland coast the abovementioned suggestion that the Twofold Bay and Port Phillip fish are distinct, but that both overlap with those at Lakes Entrance. This is a reasonable finding, and it is also acceptable because these three localities yielded the largest samples, each of which was accumulated over a period of years. It may also be significant that there is a regular, if slight, increase in mean vertebra number westwards along the coast, if these three localities alone are considered. The Coffin Bay mean would fit satisfactorily into such a cline.

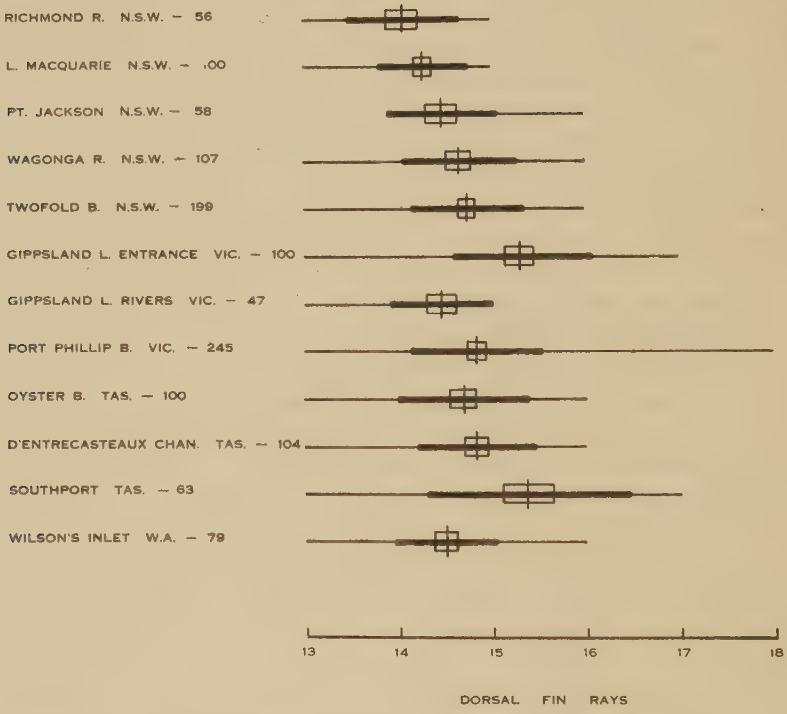


Fig. 10.—Summary of data on anchovy dorsal fin-ray counts, cf. Fig. 9.

As indicated elsewhere (Section V (*b*)), Victorian anchovies have larger scales than Tasmanian ones and those from New South Wales are larger still, for comparable sizes of fish. The reason for this is probably that the number of scale-rows along the body increases from north to south, but it was not possible to establish it because hardly any specimens still had all their scales when examined. It was shown also (Sections III (*c*) (vi) and IV (*b*)) that the growth rate was virtually the same at St. Helens as at Port Phillip, whereas that in the Gippsland rivers was slightly greater. The sex ratio seems to vary considerably between some localities at the same season (Section III (*b*)), but this cannot definitely be taken to indicate distinctions between populations.

Counts of dorsal fin rays were made for 1,258 fish, and the data are set out in Table 21 and Figure 10. All locality-samples consist of 47 or more fish. It will be seen that the whole series presents a very similar picture to that based on the vertebral count means, but not quite so obvious at first sight because of a lesser tendency to variation in this character. For instance, the variation is not sufficient to distinguish subspecies. The sample means increase regularly down the whole New South Wales coast but are irregular further south. The only Western Australian sample mean is comparable with those for New South Wales, as was also the case with the vertebrae. The Gippsland rivers mean is almost one ray less than that for the Lakes Entrance fish, although each locality-sample consisted of material collected only on a single date. This character obviously varies in much the same way as the number of vertebrae, only in less degree, and again it is evident that there are variations not associated with locality, which are more marked in the southern waters. Because of this, and the lower number of locality-samples and the fewer observations for many of them, the data are less suitable for recognition of local populations than are those on vertebral numbers.

TABLE 21

RAW DATA AND STATISTICS OF ANCHOVY DORSAL FIN RAY COUNTS

Locality	Dorsal Fin Rays						n	A.M.	S.D.	S.E.
	13	14	15	16	17	18				
Richmond R. (N.S.W.)	8	36	12	—	—	—	56	14.07	0.599	0.080
L. Macquarie (N.S.W.)	1	70	29	—	—	—	100	14.28	0.473	0.047
Pt. Jackson (N.S.W.)	—	32	24	2	—	—	58	14.48	0.570	0.075
Wagonga R. (N.S.W.)	3	35	64	5	—	—	107	14.66	0.613	0.059
Twofold B. (N.S.W.)	1	66	115	17	—	—	199	14.74	0.611	0.044
Gippsland Lakes Entrance (Vic.)	1	11	46	40	2	—	100	15.31	0.734	0.074
Gippsland Lakes rivers (Vic.)	1	23	23	—	—	—	47	14.47	0.546	0.079
Port Phillip Bay (Vic.)	5	64	146	28	1	1	245	14.83	0.696	0.045
Oyster Bay (Tas.)	2	38	49	11	—	—	100	14.69	0.692	0.070
d'Entrecasteaux Channel (Tas.)	1	28	64	11	—	—	104	14.82	0.620	0.061
Southport (Tas.)	3	10	20	21	9	—	63	15.37	1.067	0.135
Wilson's Inlet (W.A.)	1	39	38	1	—	—	79	14.49	0.552	0.062

The general pattern of locality variation in number of vertebrae and dorsal fin rays for this species, i.e. increasing towards higher (colder) latitudes and (in the Gippsland Lakes) towards waters of higher salinity, is the same as that which is usually found for other species showing variation (see Vladykov 1934). Because of this correlation of meristic characters with environmental factors, and of experimental evidence such as that reported by Gabriel (1944), it is believed that environmental factors play the major, though not the exclusive, part in determining the means of these characters in the minor groupings of a fish species. Year-class variation at the same locality provides further evidence. Temperature is certainly one of the major factors, and it is interesting in this case to note that vertebra numbers decline into warmer waters on both the eastern and western Australian coasts, where the means are rather similar at the same latitude. As Mayr says (1942, p. 63), "The pheno-

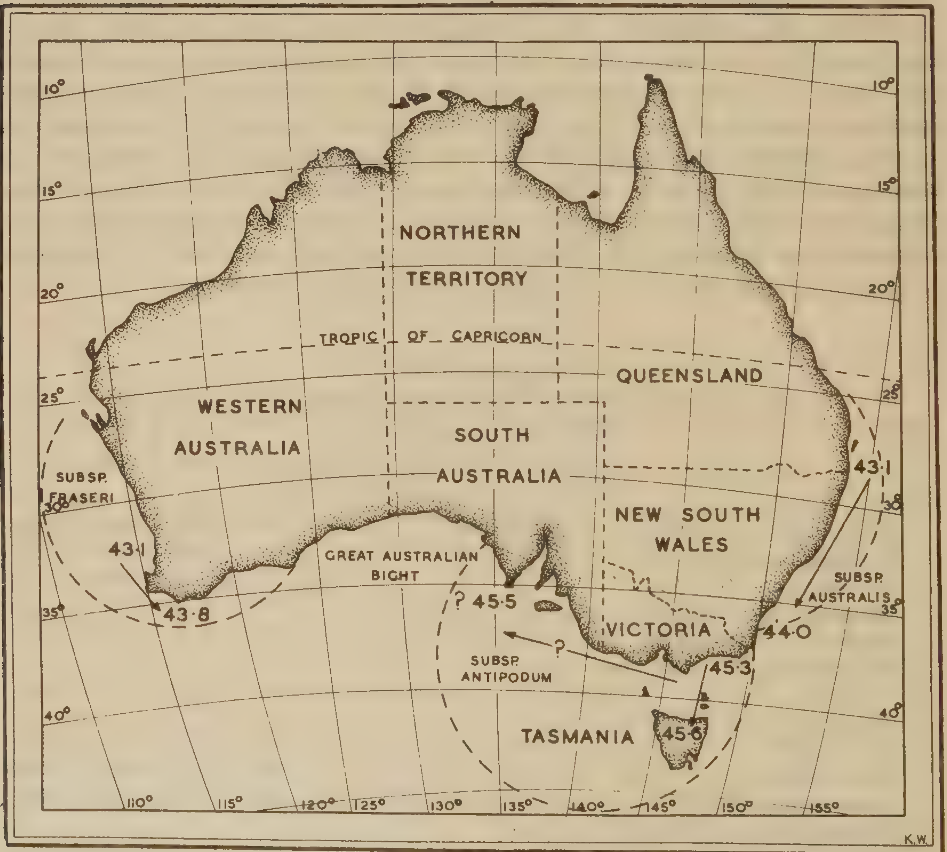

10°
15°
20°
25°
30°
35°
40°
NORTHERN
TERRITORY
TROPIC OF CAPRICORN
QUEENSLAND
WESTERN
AUSTRALIA
SOUTH
AUSTRALIA
NEW SOUTH
WALES
VICTORIA
TASMANIA
GREAT AUSTRALIAN
BIGHT
SUBSP.
FRASERI
SUBSP.
AUSTRALIS
SUBSP.
ANTIPODUM
43·1
43·8
? 45·5
?
43·1
44·0
45·3
45·6
110°
115°
120°
125°
130°
135°
140°
145°
150°
155°
K.W.

Fig. 11.—The approximate disposition of anchovy subspecies in Australian waters. Arrows indicate clines by mean vertebra numbers.

typical variant . . . usually has a rather small range at any one locality, but crops up again and again wherever the same or a similar combination of environmental factors occurs."

To sum up, three distinct subspecies, *australis*, *antipodum*, and *fraseri* are recognized. *E. a. australis* ranges along the eastern Australian coast down to but not including the Twofold Bay region. *E. a. antipodum* occurs in this southernmost New South Wales area and throughout Victorian, Tasmanian, and probably all South Australian coastal waters. *E. a. fraseri* is found in Western Australia, where its characters are practically the same as for *australis*. As shown elsewhere, *antipodum* spawns mainly in summer and in enclosed waters, but *australis* tends to begin spawning earlier and mainly in the open sea, at any rate in the northern part of its range. The position is not known for *fraseri*, but it would not be surprising if it ran parállel to that for *australis*. Within each subspecies there are local populations which overlap. It is not clear how many there are, but probably the number of such components of each subspecies is not large. There is also a special brackish-water population of *antipodum* in the rivers flowing into the Gippsland Lakes, which has little or no connection with the fish that are found at Lakes Entrance.

Engraulis australis fraseri n. subspecies is formally defined as comprising fish of that species occurring in the waters of Western Australia (and possibly western South Australia), having mean vertebra numbers of less than 44, including the urostyle, in samples of 50 or more individuals. In this character it agrees with *E. a. australis* (White) of eastern Australia, but there is no geographical connection between the two. The species does not extend around the north coast of Australia, while, on the south coast, the middle of its range is occupied by *E. a. antipodum* Gunther, having mean vertebra numbers 44.9 or more, in samples of 50 or more fish.

VIII. Comparison With the Biology of Anchovies Overseas

The European and Mediterranean anchovy, *Engraulis encrasicholus* (L.), has been the subject of fairly extensive research. Unfortunately much of this has been reported in journals which are not available in Australia. The only papers dealing with original work that the writer has been able to read are some by Fage (1911, 1935, 1937), and Arné (1931). However Meek (1916, pp. 107-111) and De Buen (1931) gave detailed summaries of all previous work in western Europe, and there are brief references to earlier Russian studies in a paper by Kleinenberg (1937). The following is a summary of the results of the European research.

At least three populations are recognizable on morphological grounds (number of vertebrae and dorsal rays, body proportions, etc.), namely in the Atlantic and the west and east Mediterranean. The main spawning season is broadly the summer in at least the first two areas. In the western Mediterranean reproduction takes place at sea, and often well offshore. The larvae and postlarvae drift inshore, and the fish remain in the immediate coastal waters until the winter. Then, if they have attained a certain size (i.e. excluding the late individuals hatched in autumn), they move further offshore and deep down, to 100 or 150 metres below the surface. They reappear in the surface waters in summer and become sexually mature at the age of one year. In the second winter there is again a descent followed by a reappearance at the surface in the following spring and summer. Fish older than two years are not known. During their surface phases the fish often enter the estuaries, but are not known to spawn there, and (apart from late-spawned O-group individuals) they always leave in winter. It is thought that the winter movement is to avoid the lower temperatures of the shallows and surface waters. Studies on the growth rate, by length observations and scale-readings, indicate that the fish measure 12 to 14 cm. of (apparently) *total* length at the age of one year, and 15 to 17 cm. at two. The scale-rings are formed in winter, when (as shown from length studies) very little growth takes place.

In the Atlantic, however, the principal spawning area is (or was) the Zuyder Zee, although some eggs have been found in the open sea. All the anchovies go out to sea with the approach of winter, returning in the spring. It is believed that this is again because the shallow waters are too cold in winter. During their sojourn at sea, the fish probably migrate into other parts of the North Sea and the English Channel. They are first mature at one year. Sizes (apparently *total* lengths) at one, two, and (probably) three years of age are respectively about 12 to 15, 15 to 18, and 18 to 21 cm. Larger and older fish are not known. The age determinations are based partly on length and partly on scale studies. The scale-rings are formed in winter, which is again the season of minimum growth. When the Zuyder Zee was reclaimed the mouths of neighbouring rivers began to be used by anchovies as spawning areas. Anchovies occur in the Bay of Biscay and may constitute a separate population there, but they have not had much study.

The anchovy of the Azov Sea leaves that area in winter for the deeper and warmer waters of the Black Sea.

It will be seen that there are apparently some important differences between the life histories of the European and Australian species. There are also several points of general similarity, notably the tendency for the fish to spawn in enclosed waters at higher latitudes and out to sea at lower latitudes, and to move out of the immediate coastal zone in winter, although the younger fish in Australian waters do not do this. There are also several populations in both areas. However there appears to be a very important difference in the growth rate. Taking the European data on the one hand and the Victorian (converted to total length) on the other, it appears that the growth rate of the European species is almost twice as fast as that of *E. australis,* as shown by the following comparison:

	Europe	Australia
Total length at one year	12-15 cm.	7-8 cm.
Total length at two years	15-18 cm.	9 cm.
Total length at three years . ..	18-21 cm.	10-11 cm.
Maximum total length	21 cm.	16 cm.

This finding is rather surprising, in view of the fact that the pilchard was found to grow, in Australian (New South Wales) waters, at a rate which was not substantially different from that of a closely related species in Europe; actually the growth rate was faster than that of the pilchard in the Mediterranean but slower than that in British waters (Blackburn 1949, pp. 68-74). As explained above, it was not possible to consult many of the original papers dealing with the European anchovy research, but the accounts available indicate that there was independent work by at least two authors (Redeke in Holland, Fage in the Mediterranean) whose findings agreed very well. There are, however, grounds for some misgivings about a drawing of a scale (Fig. 1) in Fage's 1911 paper, which the present writer would take to have probably one ring although Fage regarded it as showing none. This scale came from one of the fish which Fage regarded as having been hatched very late in the spawning season and on this account not receiving the imprint of the first winter upon their scales. According to Fage, these fish do winter in the coastal waters instead of going back out to sea as the others of the same brood do (see above), and thus, if it could be supposed that he (and Redeke) both consistently failed to count the first winter ring, there might be at least one full year of inshore life before the fish entered upon its period of alternating inshore and offshore phases. This would make the life history much more comparable with that of the Australian species, although the growth rate of the latter would still be less. However, it would be presumptuous to discuss the matter further at present.

The only other species of *Engraulis* about whose life history anything has been published is *E. mordax* Girard of California. The information is very meagre, being that given incidentally by Hubbs (1925) in his study of anchovy populations. He states that the "ocean" subspecies occurs in San Francisco Bay only in the warmer months of the year, when it apparently spawns near the entrance. In the winter it seems to move out to sea. There are indications of a somewhat parallel movement as regards the "bay" subspecies, since that is found nearly down to the entrance in winter, but in spring probably "migrates, as anchovies have the habit of doing, into waters of reduced salinity" (p. 21). As regards the "ocean" subspecies, the situation is obviously rather comparable with that of *E. australis* in Victoria and Tasmania, and *E. encrasicholus* in the North Sea. As indicated above, the life history of *E. australis* in the warmer waters of Australia would appear more like that of *E. encrasicholus* in the Mediterranean, spawning taking place at sea in both cases.

IX. POSSIBILITIES OF COMMERCIAL DEVELOPMENT

The author is satisfied that the occurrences of Australian anchovies are sufficient to yield a very significant addition, probably of the order of several million pounds, to the Australian annual fish catch. This and more could be said of several other species at present little exploited in our waters, but for most of them there are still problems of catching technique to be solved. This does not apply to the anchovy. In Port Phillip Bay at least, as the history of recent operations shows (see Section III (*a*)) and as the writer has confirmed from personal observation, hundreds of tons are apt to lie in shallow waters within easy reach of haul seine nets, and there are local fishermen who are able to catch them and are anxiously seeking outlets in the trade. Similar occurrences are almost certainly present elsewhere, and some fishermen at other centres are also keenly interested. If the fishermen could be assured of an outlet for large catches, of the order of hundreds of tons annually, they could accept a low price.

Anchovies could be used for "straight" canning (as "sardines" for instance), for fish paste, or for live-bait for tuna fishing. Up to the present they have been used by processors for flavouring in fish pastes, which mostly have barracouta as a base. Such pastes appear to be holding their own against imported ones on the local market, but this outlet accounts for a small part only of the anchovies that are freely available for capture. "Straight" canning presents a problem of handling, i.e. the heading of the individual fish. For this reason canners may find it necessary to handle the larger fish only in this way, possibly turning the small ones into paste. If this were done the problem should be no greater than that which the packers of Norwegian sardines must have solved many years ago, since those fish are fairly comparable with the medium and large-sized Australian anchovies. As for live-bait for tuna, the suitability of the anchovy has already been demonstrated by small-scale fishing experiments in Australian waters (Flett 1944). For this purpose the fish require to be carried alive in tanks aboard the tuna fishing boat, perhaps for some weeks at a time. Fish which have not lost many scales when being caught and scooped into the tanks seem to live quite well, although badly scaled fish die. Since the larger anchovies lose their scales less easily than the smaller, the former would again be preferable for this purpose.

Anchovies have occasionally been caught in lampara nets in Australian waters, but, inasmuch as they often occur in very shallow waters, the ordinary haul seine (with ½ in. mesh) is quite appropriate fishing gear. In Port Phillip Bay, these nets are generally "bunted up" in the water and not hauled on to the beach. This type of fishing could probably be developed to fish still deeper waters if necessary, when the gear would tend to approximate to a lampara net in form and in method of use. The lampara would probably be needed to exploit the offshore winter shoals, e.g., off Lakes Entrance.

Some inshore waters which have come especially to notice, as being areas frequented by large occurrences of anchovies, are Port Phillip Bay and Lakes Entrance (Vic.), Twofold Bay (N.S.W.), Southport (Tas.), and Wilson's Inlet (W.A.). There are many other places which are probably similar, e.g. Westernport (Vic.), St. Helens (Tas.), and Cowell (S.A.). As the foregoing studies show, in at least some and in probably all of these areas there are some anchovies available, in some part of the bay or inlet, in any season of the year. Furthermore, in Port Phillip Bay at least, natural fluctuations do not seem to be as violent as they are for some other species. In Port Phillip there are small and large fish available in the warmer months of the year, at Hobson's Bay and Geelong respectively, and large ones also available in the colder months on the eastern beaches and possibly elsewhere. If fish were required from this area for tuna fishing it would probably be best to try the neighbourhood of Geelong, where large fish are available in summer and autumn (the main tuna season in south-eastern Australia) and can be caught by haul seine. Lakes Entrance and Twofold Bay, especially the former, usually have medium-sized and large anchovies available in the inshore waters in the spring and summer. At Southport and St. Helens the fish leave the shallows rather early, before the tuna are most abundant in the adjacent waters, but it has been shown by experiment that anchovies can be kept alive in floating pens or cages for over four months. It is obvious that there are considerable possibilities for utilizing anchovies as live-bait.

It does not appear that anchovies could be utilized for commercial oil reduction. The analyses of samples from various places revealed oil percentages by weight (of the whole, or wet, fish) ranging only from 0.6 to 3.0 (see Blackburn 1941, pp. 122, 135). The estimated yield of oil, from the catches represented by these samples, ranged from 1.5 to 7.4 imperial gallons per long ton, which would not be economical even if the turnover of fish was of a much higher order than anything that can reasonably be expected. All the samples consisted mainly of fish at least two years of age and, since oil content generally increases with size of fish, one would expect the Hobson's Bay yearlings, for example, to have even less. For fish of comparable size, it would also be expected that the oil content would be least in the spawning season and greatest between spawnings. It is thus probably significant that the sample containing the highest proportion of mature fish (from Twofold Bay in February) had the lowest oil content of any, and that taken most nearly midway between spawning seasons (from Oyster Bay in June) had the highest.

X. CONCLUSIONS

(*a*) The anchovy *Engraulis australis* (White) occurs in all Australian coastal waters south of the Tropic of Capricorn (and also in New Zealand). The only significant fishery is in Port Phillip Bay, but the demand is very limited and the annual catch has been only of the order of 100 tons at most.

(*b*) In Victorian waters the fish attain an average body length of about 50, 62, 75, 90, and 102 mm. at about ½, 1½, 2½, 3½, and 4½ years of age, equivalent to 2.3, 2.9, 3.5, 4.2, and 4.7 inches total length. Most of the growth occurs in the spring and summer months. Nearly all are mature at the end of the first year. The main spawning season is the late spring and summer, and spawning takes place principally in the bays and inlets. There are variations in sex ratio between different localities at this season.

(*c*) In Port Phillip, anchovies under 2 years of age are not commonly found outside the upper reaches of the bay, where they are usually most conspicuous in the warmer months. Probably the same applies in other Victorian inlets. From the age of about 2, they move towards the entrance waters, and from the age of about 2½ (third winter) there is a tendency for them to move out to sea in winter and return during spring. This tendency increases with age. Many 2½-year and some older fish remain in the bay in winter, where they form large shoals off the eastern beaches. The seaward migration has not actually been observed at Port Phillip, but occurs at Lakes Entrance, Westernport, and probably elsewhere.

(*d*) In Tasmania, the growth rate and life history are apparently very much the same as in Victoria.

(*e*) In New South Wales and Queensland waters the spawning season tends to commence earlier, and possibly to be earlier altogether, than in Victoria and Tasmania. This tendency becomes progressively more obvious for more northern localities. Also, apart possibly from the coast south of Sydney, for which full data are lacking, most of the spawning occurs at sea instead of in the inlets. The life history is therefore probably different in many other ways (e.g. with regard to movements) from that in Victoria and Tasmania, but the facts have not been established definitely. The growth rate, however, is approximately the same.

(*f*) Virtually nothing is known about the biology of the species in South Australia and not very much in Western Australia, except that the growth rate appears to be broadly similar to that of other areas.

(*g*) The largest recorded anchovy (from Tasmania) measured 136 mm. in body length, equivalent to 6.2 inches total length.

(*h*) There are three well-marked subspecies of *Engraulis australis* in Australia. One, *E. a. australis* (White) occurs on the coasts of Queensland and New South Wales, excluding the southernmost (Twofold Bay) region. Another, *E. a. antipodum* Gunther, ranges from Twofold Bay through Victorian, Tasmanian and probably most South Australian waters. The third, *E. a. fraseri* n. subsp., occurs in Western Australia. The subspecies *australis* and *fraseri* have mean total vertebra numbers (including urostyle) between 43 and 44, for samples of 50 or more fish. For *antipodum*, similar means range between 44.9 and 46. There is a general tendency for vertebra number to increase towards the south, and the

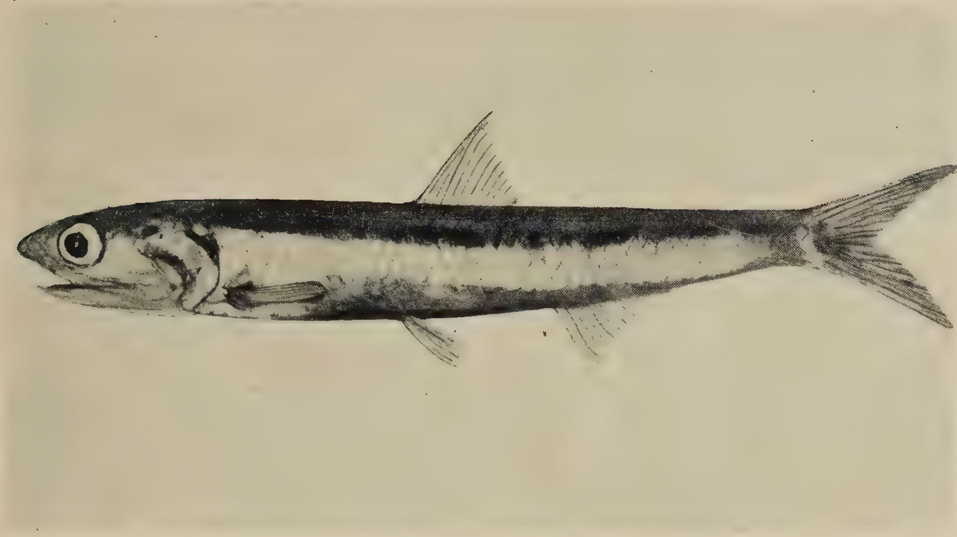


Fig. 1

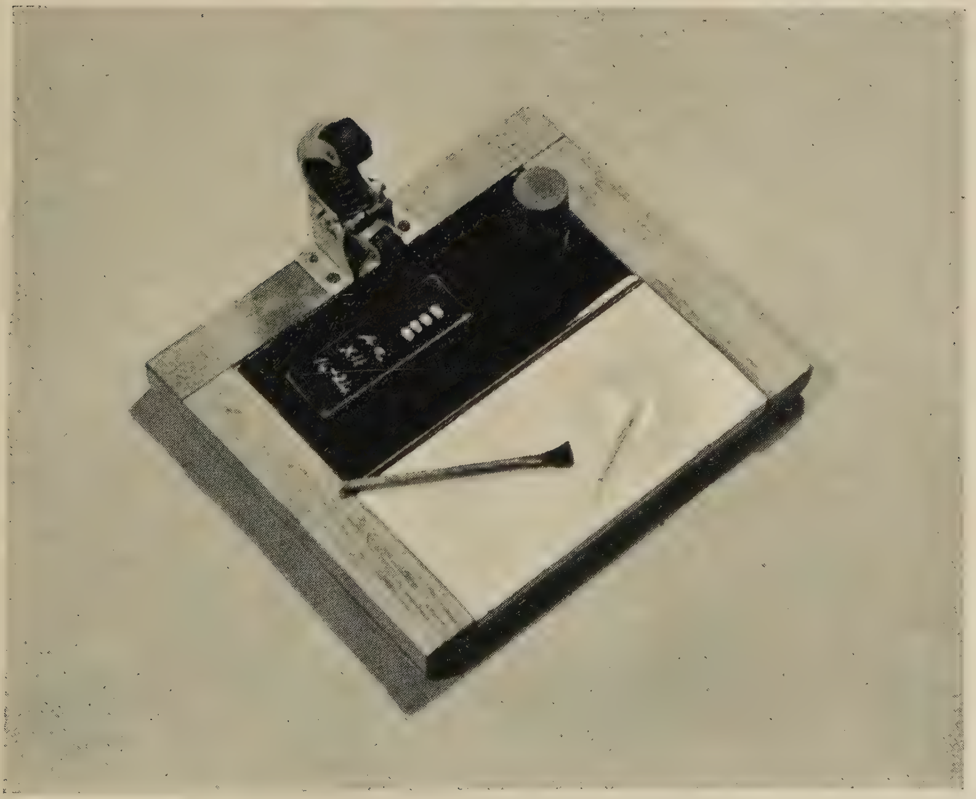
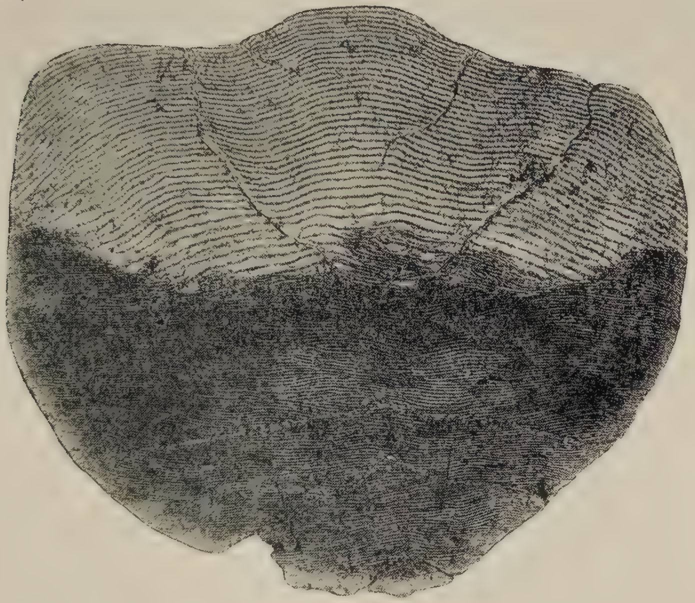


Fig. 2

BLACKBURN.—A BIOLOGICAL STUDY OF THE ANCHOVY, ENGRAULIS AUSTRALIS (WHITE) IN AUSTRALIAN WATERS



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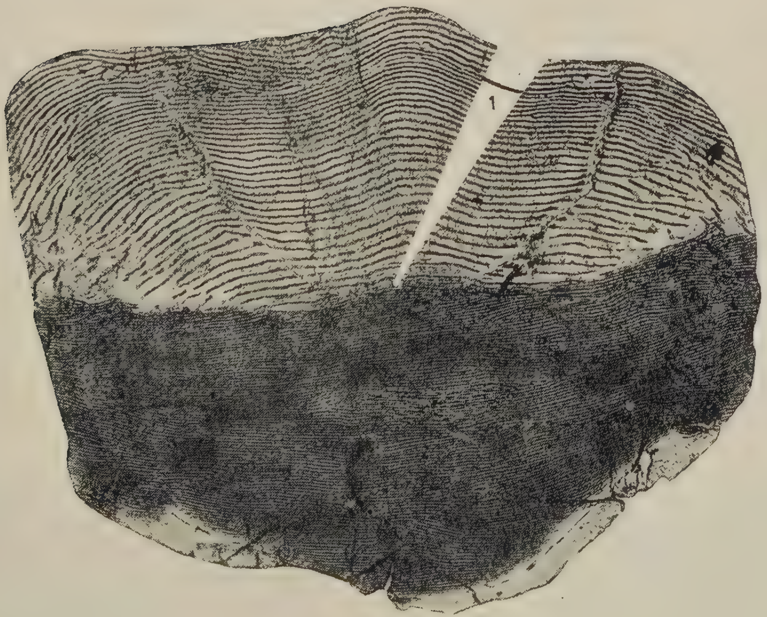

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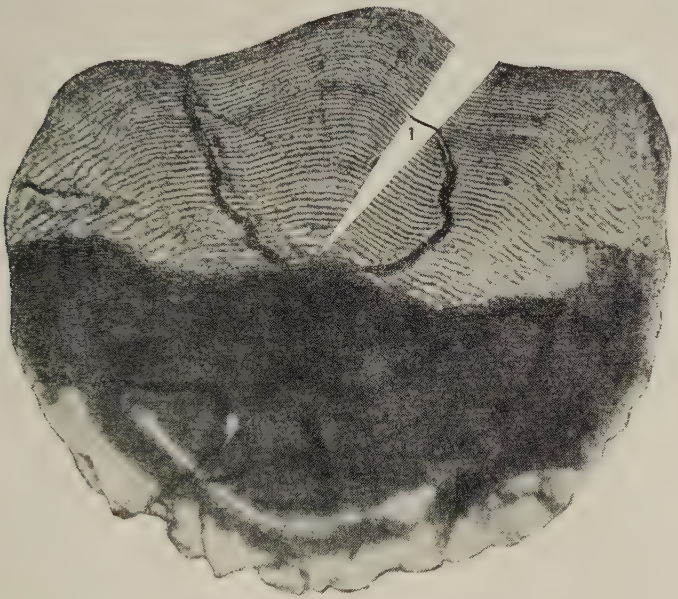
BLACKBURN.—A BIOLOGICAL STUDY OF THE ANCHOVY, ENGRAULIS AUSTRALIS (WHITE)



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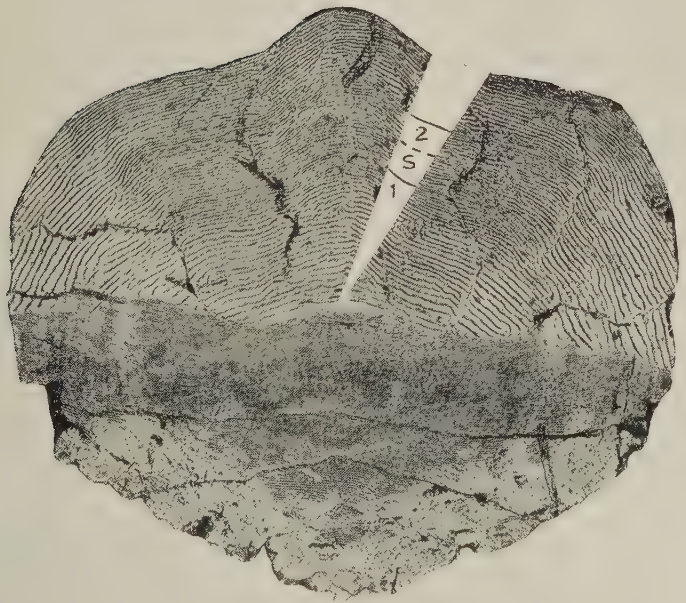

2

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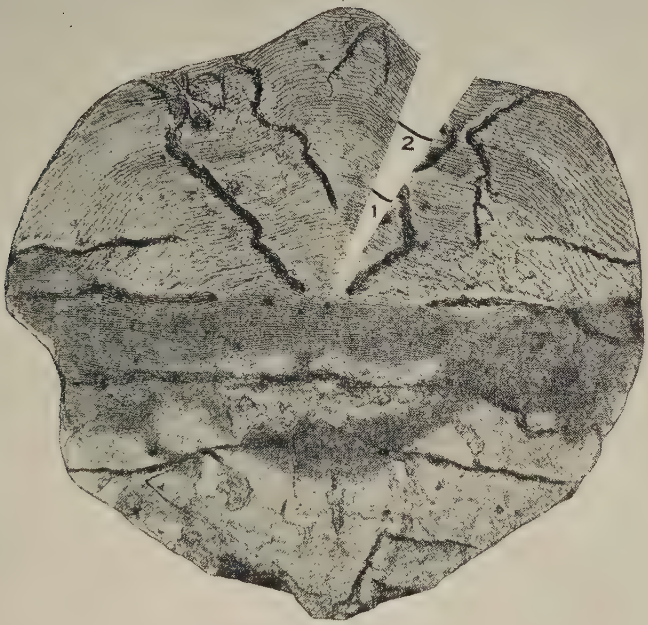

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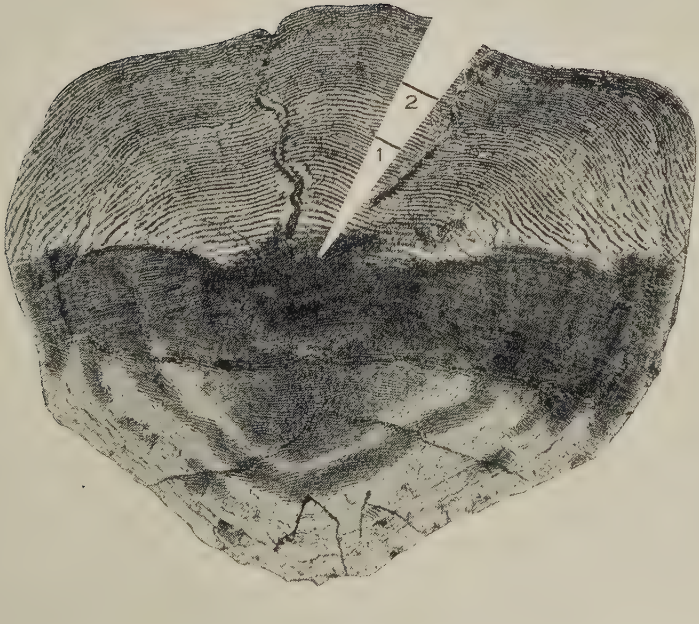
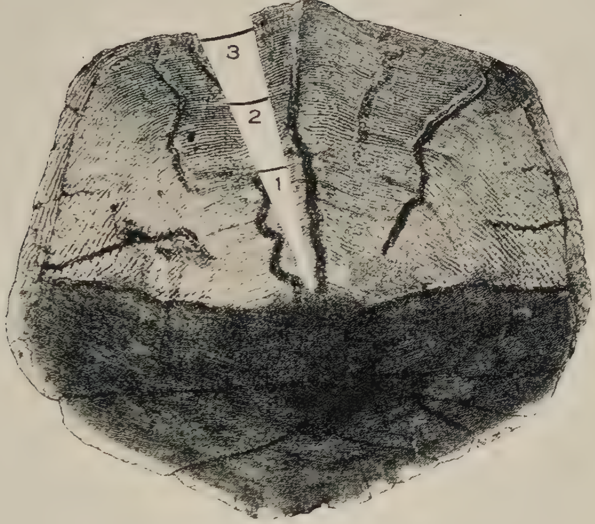


2

BLACKBURN.—A BIOLOGICAL STUDY OF THE ANCHOVY, ENGRAULIS AUSTRALIS (WHITE) IN AUSTRALIAN WATERS



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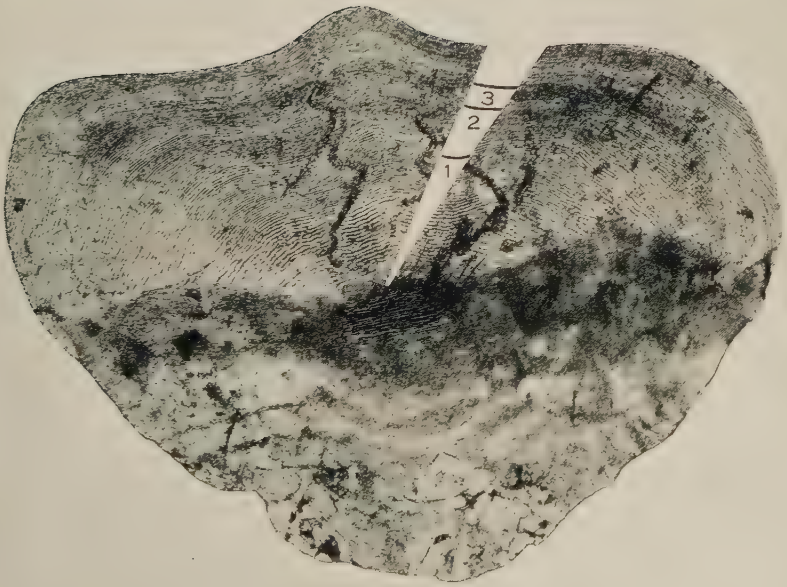

2

BLACKBURN.—A BIOLOGICAL STUDY OF THE ANCHOVY, ENGRAULIS AUSTRALIS (WHITE) IN AUSTRALIAN WATERS

same applies to the number of dorsal fin rays. Within the range of each subspecies there are subsidiary overlapping populations. There is also a special brackish-water population in the rivers flowing into the Gippsland Lakes, whose mean vertebral and dorsal fin ray numbers are respectively about ⅔ and 1 less than those for fish occurring at Lakes Entrance.

(*i*) There is a very general resemblance between the life history of *E. australis* and the European anchovy, *E. encrasicholus*. However, the reported growth rate of the latter is nearly twice as fast, and there seem to be other important differences as to movements at different stages of life.

(*j*) Anchovies could be used commercially for canning whole, fish paste, or live-bait for tuna fishing. The oil content, however, is always much too low for profitable reduction. In Port Phillip Bay the fish are available in large quantities and have been taken by local fishermen in quantities up to 5 or 6 tons per beach-seine haul. These fishermen are anxiously seeking trade outlets. Fish are available at all times of the year. Other localities where anchovies occur plentifully include Lakes Entrance and Westernport (Victoria), Twofold Bay (New South Wales), Southport and St. Helens (Tasmania), Cowell (South Australia) and Wilson's Inlet (Western Australia). In some of these places there are men who have already done some anchovy fishing.

In addition, there are some conclusions of more academic interest concerning the age investigations with scales:—

(*k*) The scales are rather like those of salmonoids, especially in the appearance of the annual rings. This makes them much easier to read than those of many other Australian species. 2,312 scales were examined from 764 fish, for all localities combined, and the age was determined without doubt for 655 fish (86 per cent.). Most of the doubtful cases concerned fish over 9.0 cm. body length. The number of striations tends to be lower on scales from the anterior part of the trunk, and these scales are consequently the least easily read. Secondary rings are not important, but where they do occur there are signs of them on most scales examined from the same fish.

(*l*) Scale size declines towards the south in fish of the same length. and so the fish-length/scale-length relationship is not the same in all areas. In Victorian waters, however, the ratio is practically constant for fish over 5.5 cm. body length.

(*m*) At least in Victoria, the principal season of formation of all the annual rings is the winter, although some developing rings may be found at almost any season.

(*n*) There is very considerable variation in size-for-age, as shown by a study of calculated lengths at successive winters. There are effects of variation associated with different sizes in the age-group, age-groups, localities and possibly year-classes and sexes. The differences between age-groups are of the usual type (Lee's Phenomenon), which in this case is due to the fact that larger fish retain their scales more easily than small ones; the younger age-groups are thus represented in the scale studies by fish of larger than average size. There is no growth compensation, and some fish appear to grow consistently faster than others throughout life. However, this is probably due merely to small differences in age between individuals hatched in the same season.

XI. ACKNOWLEDGMENTS

Thanks are due to many people who have given valuable assistance in connection with the anchovy investigations. In the Division of Fisheries of the C.S.I.R., considerable assistance was given by Messrs. G. Clark, W. J. Fletcher, S. Fowler, I. S. R. Munro, A. Proctor, and K. Wilson, of whom the two last were responsible for the photographs (except Plate 1, Fig. 2, which is by Mr. D. Falconer) and line figures. Mr. A. D. Butcher, Director of Fisheries and Game for Victoria, was also extremely helpful with material and information. Fishermen who assisted particularly were Messrs. T. Briggs, C. Button, T. Clyde, A. Defina, W. Hughes, H. Klauer, and B. Sutherland. Laboratory facilities were provided by the Victorian Fisheries and Game Department and the Zoology Department of the University of Melbourne. The portions of the paper dealing with the application of statistical methods were checked by Mr. R. Leslie, of the Section of Mathematical Statistics, C.S.I.R.O.

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APPENDIX A

MEANS OF SCALE-LENGTHS (S) AND OF CORRESPONDING FISH-LENGTHS (L), FOR SUCCESSIVE HALF-CM. INTERVALS OF L, FOR VICTORIAN MATERIAL OF ALL YEAR-CLASSES COMBINED

Length-group (cm.)	Mean Fish-length, L (mm.)	Mean Scale-length, S (mm.)	No. of Observations
4.5	47.14	0.85	7
5.0	52.00	1.16	22
5.5	57.50	1.56	52
6.0	62.29	1.79	149
6.5	67.23	1.96	151
7.0	72.23	2.15	154
7.5	76.64	2.35	170
8.0	81.52	2.51	84
8.5	86.86	2.22	73
9.0	92.60	2.63	84
9.5	97.61	2.61	137
10.0	102.08	2.97	124
10.5	106.84	3.14	116
11.0	111.49	3.24	59
11.5	115.50	3.35	14
		Total	1396

APPENDIX B

MEANS OF SCALE-LENGTHS (S) AND OF CORRESPONDING FISH-LENGTHS (L), IN MM., FOR SUCCESSIVE HALF-CM. INTERVALS OF L, YEAR-CLASSES SEPARATE; VICTORIAN MATERIAL

Length-group (cm.)	1944-45			1943-44			1942-43			1941-42			1940-41			1939-40			1938-39			1937-38		
	L	*S*	No.	*L*	*S*	No.	*L*	*S*	No.	*L*	*S*	No.	*L*	*S*	No	*L*	*S*	No.	*L*	*S*	No.	*L*	*S*	No.
4.5	47.14	0.85	7																					
5.0	50.80	1.09	10	53.00	1.15	4	53.00	1.26	8															
5.5	57.33	1.47	9	58.43	1.33	7	57.28	1.63	32	58.00	1.68	4												
6.0	62.34	1.59	32	62.79	1.78	23	62.11	1.80	86	62.00	2.12	5												
6.5	66.68	1.98	22	67.66	1.86	26	67.30	1.97	73	66.74	2.08	23	68.00	1.73	5									
7.0	70.00	1.97	8	71.29	2.02	17	71.91	2.10	45	72.52	2.29	54	73.26	2.17	23	73.43	2.19	7						
7.5				76.73	2.33	11	76.93	2.24	21	76.69	2.41	112	75.67	2.93	12	76.50	1.70	2	77.00	2.15	4			
8.0				80.00	1.89	3	82.00	2.30	22	81.14	2.54	21	81.24	2.82	29	—	—	—	81.50	1.94	4			
8.5				85.00	1.78	2	86.17	2.14	6	87.54	2.18	31	86.56	2.42	6	86.50	2.32	10	86.00	2.24	8			
9.0							94.00	3.19	4	92.52	2.42	31	92.68	2.57	28	92.00	2.85	3	92.47	3.12	15	92.00	2.15	3
9.5							95.00	2.21	4	96.75	2.49	44	96.49	2.69	45	97.88	2.67	17	98.00	2.80	4	99.00	2.40	2
10.0							101.00	3.46	8	101.55	3.07	20	102.04	2.78	28	102.57	2.55	14	—	—	—	103.00	3.43	1
10.5										105.90	3.17	10	106.65	3.21	32	107.00	2.99	20	109.00	2.48	3			
11.0													110.73	3.41	15	111.32	3.00	19	111.00	2.96	2			
11.5													116.00	2.96	4				115.00	3.11	3			

APPENDIX C

DETAILS OF VICTORIAN ANCHOVY SAMPLES

Date	Locality	No. Measured	How Procured
1. ix. 37	Chelsea	80	? Beach seine
14. xii. 37	Seaford	2	? Beach seine
12. viii. 38	Off Lakes Entrance	12	*Ex* barracouta
9. ii. 39	Cliffy Is.	13	*Ex* southern bluefin tuna
†—. vi. 41	Mitchell R.	3	(From Vic. Fisheries Dept.)
†16. vii. 41	Off Lakes Entrance	12	*Ex* barracouta
†1. x. 41	Gippsland Lakes	5	(From Vic. Fisheries Dept.)
12. xi. 41	Geelong	8	Melbourne market
†12. xi. 41	Pt. Melbourne	11	Melbourne market
†18. i. 42	Mitchell R.	1	(From Vic. Fisheries Dept.)
27. i. 42	Tom's Creek	1	(From Vic. Fisheries Dept.)
†20. iii. 42	Geelong	13	Melbourne market
†21. iii. 42	Pt. Melbourne	22	Melbourne market
†26. iii. 42	Pt. Melbourne	10	Melbourne market
†14. vi. 42	Pt. Melbourne	9	Melbourne market
†15. vi. 42	Mitchell R.	6	(From Vic. Fisheries Dept.)
†21. vi. 42	Pt. Melbourne	45	Melbourne market
†29. x. 42	Tambo R.	2	(From Vic. Fisheries Dept.)
23. xi. 42	Geelong	2	Melbourne market
24. xi. 42	Geelong	32	Melbourne market
16. xii. 42	Pt. Melbourne	10	Melbourne market
†19. x. 43	Pt. Melbourne	499	Melbourne market
†15. xi. 43	Pt. Melbourne	510	Melbourne market
†7. xii. 43	Pt. Melbourne	581	Melbourne market
†21. i. 44	Pt. Melbourne	466	Melbourne market
†21. ii. 44	Pt. Melbourne	461	Melbourne market
†27. iii. 44	Pt. Melbourne	451	Melbourne market
†5 iv. 44	Nicholson R.	44	(From Vic. Fisheries Dept.)
†25. iv. 44	Pt. Melbourne	529	Melbourne market
†25. v. 44	Pt. Melbourne	496	Melbourne market
†25. vi. 44	Pt. Melbourne	510	Melbourne market
15. vii. 44	Off Pt. Fairy	3	*Ex* barracouta
†28. vii. 44	Pt. Melbourne	557	Melbourne market
6. viii. 44	Off Pt. Fairy	5	*Ex* barracouta
7. ix. 44	Lakes Entrance	33	Beach seine
12. ix. 44	Lakes Entrance	69	Beach seine
15. ix. 44	Pt. Melbourne	505	Melbourne market
19. x. 44	Off Pt. Fairy	1	*Ex* barracouta
†3. xi. 44	Geelong	244	Melbourne market
†9. xi. 44	Pt. Melbourne	347	Melbourne market
†23. xi. 44	Nicholson R.	93	(From Vic. Fisheries Dept.)
†4. xii. 44	Tambo R.	122	(From Vic. Fisheries Dept.)
†8. xii. 44	Pt. Melbourne	292	Melbourne market
†8. xii. 44	Lakes Entrance	324	Melbourne market
†20. i. 45	Lakes Entrance	221	Melbourne market
†16. ii. 45	Pt. Melbourne	702	Melbourne market

APPENDIX C (CONTINUED)

Date	Locality	No. Measured	How Procured
15. iii. 45	Pt. Melbourne	671	Melbourne market
15. iii. 45	Off Pt. Fairy	9	*Ex* barracouta
4. v. 45	Off Pt. Fairy	1	*Ex* barracouta
†7. v. 45	Pt. Melbourne	510	Melbourne market
†28. v. 45	Pt. Melbourne	499	Melbourne market
14. vi. 45	Off Pt. Fairy	8	*Ex* southern bluefin tuna
†18. vi. 45	Queenscliff	247	Melbourne market
†27. vi. 45	Pt. Melbourne	451	Melbourne market
†11. vii. 45	Flinders	531	Melbourne market
†22. vii. 45	Flinders	216	Melbourne market
†9. viii. 45	Flinders	483	Melbourne market
†4. ix. 45	Flinders	303	Melbourne market
26. ix. 45	Off Pt. Fairy	3	*Ex* barracouta
24. x. 45	Lakes Entrance	204	Melbourne market
7. i. 46	Pt. Melbourne	4	Melbourne market
14. i. 46	Pt. Melbourne	2	Melbourne market
†30. i. 46	Pt. Melbourne	512	Melbourne market
†4. ii. 46	Pt. Melbourne	521	Melbourne market
6. ii. 46	Pt. Melbourne	9	Melbourne market
†23. iv. 46	Pt. Melbourne	865	Melbourne market
†23. iv. 46	Mordialloc	510	Melbourne market
8. v. 46	Pt. Melbourne	924	Melbourne market
†9. v. 46	Mordialloc	633	Melbourne market
†9. v. 46	Black Rock	450	Melbourne market
†9. v. 46	Seaford	10	(From Mr. H. Klauer)
†14. vi. 46	Williamstown	1040	Melbourne Market
†18. vi. 46	Mornington	471	Melbourne Market
2. vii. 46	Williamstown	804	Melbourne Market
31. vii. 46	Geelong	428	Melbourne Market
†8. viii. 46	Mornington	675	Melbourne Market
†13. viii. 46	Pt. Melbourne	819	Melbourne Market
3. ix. 46	Beaumaris	553	Melbourne Market
5. ix. 46	Mornington	899	Melbourne Market
†19. ix. 46	Pt. Melbourne	953	Melbourne Market
	Total	23,582	

Samples indicated † in the first column are those from which some scales were available.

Appendix D

DETAILS OF TASMANIAN ANCHOVY SAMPLES

Date	Locality	No. Measured	How Procured
†9. xii. 37	Storm Bay	5	*Ex* barracouta
5. vi. 38	Hummock I.	1	*Ex* sand flathead
28. vii. 38	West Sister I.	13	*Ex* southern bluefin tuna
29. vii. 38	Babel I.	10	*Ex* southern bluefin tuna
5. viii. 38	Babel I.	40	Lampara
11. i. 39	Spring Bay	18	Dip net
13. iv. 39	Norfolk Bay	14	Hoop net
6. vi. 39	Pt. Arthur	3	Dip net
†21. v. 40	Babel I.	4	*Ex* southern bluefin tuna
†28. vi. 40	Oyster Bay	1,465	Hoop net
5. vii. 40	Lady Barron	1	Dip net
9. iii. 41	Huon R. entrance	3	Lampara
28. iii. 41	Babel I.	13	Dip net
18. iv. 41	Southport	13	Dip net
4. v. 41	Little Taylor's Bay	1	Lampara
7. v. 41	Schouten I.	5	*Ex* southern bluefin tuna
†13. xii. 41	St. Helens	10	Dip net
†21. xii. 41	Southport	82	Dip net
†3. i. 42	St. Helens	135	Dip net
29. i. 42	St. Helens	107	Dip net
†17. ii. 42	St. Helens	88	Sample from bait pen
20. v. 42	Great Taylor's Bay	5	Lampara
†1. vi. 42	St. Helens	56	Sample from bait pen
24. viii. 42	Partridge I.	1	Lampara
†28. iv. 43	Great Taylor's Bay	102	Lampara
22. iii. 47	Southport	7	Dip net
	Total	2,202	

Samples indicated † in the first column are those from which some scales were available.

APPENDIX E

DATA AS FOR APPENDIX A, TASMANIAN MATERIAL

Length-group (cm.)	Mean Fish-length, L (mm.)	Mean Scale-length, S (mm.)	No. of Observations
6.0	63.67	1.48	6
6.5	68.50	1.48	5
7.0	72.85	1.75	46
7.5	76.84	1.82	131
8.0	81.89	2.01	116
8.5	86.72	2.29	54
9.0	91.25	2.63	8
9.5	96.64	2.83	11
10.0	—	—	—
10.5	—	—	—
11.0	110.00	2.97	3
11.5	—	—	—
12.0	121.33	4.48	3
12.5	128.00	3.87	4
		Total	387

APPENDIX F

DETAILS OF NEW SOUTH WALES AND QUEENSLAND (Q.) ANCHOVY SAMPLES

Date	Locality	No. Measured	How Procured
19. ii. 38	Ballina	5	(From N.S.W. Fisheries Dept.)
†13. iv. 39	Pt. Hacking	10	Beach seine
29. iv. 39	Ballina	17	Beach seine
†2. v. 39	Ballina	21	Beach seine
†6. vi. 39	Pt. Jackson	58	Beach seine
14. vi. 39	Twofold B.	1	Dip net
22. viii. 39	Wagonga Inlet	6	Beach seine
26. viii. 39	Green Cape-Gabo I.	15	*Ex* southern bluefin tuna
6. x. 39	Bermagui-Merimbula	10	*Ex* southern bluefin tuna
8. x. 39	Green C.-C. Everard (Vic.)	65	*Ex* southern bluefin tuna
16. x. 39	Wagonga Inlet	1	Beach seine
17. x. 39	Off Pambula	15	*Ex* southern bluefin tuna
4. xi. 39	Off Twofold B.	25	*Ex* southern bluefin tuna
†17. xi. 39	Brush I.	1	*Ex* bonito
†21. xi. 39	Wagonga Inlet	4866	Beach seine
19. i. 40	Nambucca R.	681	Beach seine
†30. i. 40	Twofold B.	155	Beach seine
6. ii. 40	Ballina	1	(Purchased)
11. ii. 40	Jervis B.	185	Lampara
13. ii. 40	Twofold B.	18	Dip net
11. iv. 40	Ballina	1	(Purchased)
†14. v. 40	Ballina	1	(Purchased)
20. vi. 40	Ballina	9	(Purchased)
11. vii. 40	Ballina	1	(Purchased)
†19. vii. 40	Pt. Jackson	791	(Sydney market)
†23. viii. 40	Pt. Jackson	428	(Sydney market)
17. ix. 40	Pt. Jackson	21	Beach seine
25. ix. 40	Merimbula	1	*Ex* sand flathead
26. ix. 40	Bateman's B.	1	Dip net
26. ix. 40	L. Illawarra	1	Prawn net
5. x. 40	Bateman's B.	4	Dip net
3. xi. 40	Beecroft Head	1	Lampara
6. xi. 40	Twofold B.	50	Dip net
19. xi. 40	Twofold B.	77	Dip net
27. xi. 40	Jervis B.	3	Lampara
†8. xii. 40	Jervis B.	13	Lampara
12. i. 41	Twofold B.	176	Dip net
†18. i. 41	L. Illawarra	7	(From N.S.W. Fisheries Dept.)
27. ii. 41	Twofold B.	28	Dip net
6. v. 41	Ballina	2	(Purchased)
11. v. 41	Tewantin (Q.)	14	Dip net
4. vi. 41	Ballina	1	(Purchased)
†13. vi. 41	Pt. Jackson	675	(Sydney market)
15. vii. 41	Fraser I. (Q.)	5	Stranded
20. vii. 41	Sandy Straits (Q.)	4	*Ex* northern bluefin tuna
†7. xi. 41	Off Twofold B.	18	*Ex* southern bluefin tuna
30. xi. 41	C. Howe	5	*Ex* southern bluefin tuna

APPENDIX F (CONTINUED)

Date	Locality	No. Measured	How Procured
†26. v. 42	L. Macquarie	215	Beach seine
†29. iv. 44	Coolangatta (Q.)	50	Dip net
†27. viii. 45	Pt. Jackson	56	(Sydney market)
†2. v. 46	Pt. Jackson	139	(Sydney market)
	Total	8,954	

Samples indicated † in the first column are those from which some scales were available.

APPENDIX G

DETAILS OF SOUTH AUSTRALIAN AND WESTERN AUSTRALIAN ANCHOVY SAMPLES

Date	Locality	No. Measured	How Procured
16. vii. 38	Dirk Hartog I. (W.A.)	1	*Ex* northern bluefin tuna
14. ii. 39	Off Coorong (S.A.)	1	*Ex* southern bluefin tuna
24. ii. 39	Kangaroo I. (S.A.)	5	*Ex* southern bluefin tuna
25. ii. 39	Porpoise Head (S.A.)	7	*Ex* southern bluefin tuna
†—. xi. 39	Nornalup Inlet (W.A.)	4	Beach seine
13. xii. 39	Kangaroo I. (S.A.)	1	*Ex* southern bluefin tuna
†1. ii. 40	Brook's Inlet (W.A.)	2	(From W.A. Fisheries Dept.)
†1. ii. 40	Nornalup Inlet (W.A.)	3	(From W.A. Fisheries Dept.)
28. iii. 40	Coffin Bay (S.A.)	4	Lampara
†14. i. 41	Bunbury (W.A.)	1	(From W.A. Fisheries Dept.)
—. vi. 41	Port River (S.A.)	1	(From S.A. Fisheries Dept.)
†—. ix. 41	Nornalup Inlet (W.A.)	17	(From D. L. Serventy)
†25. iii. 42	Wilson's Inlet (W.A.)	79	(From W.A. Fisheries Dept.)
21. ix. 43	Swan River (W.A.)	28	(From D. L. Serventy)
†7. x. 43	Bunbury (W.A.)	1	(From D. L. Serventy)
†21. vi. 44	Bunbury (W.A.)	1	(From J. Goodlad)
†3. x. 44	Swan River (W.A.)	2	(From D. L. Serventy)
†9. xi. 44	Swan River (W.A.)	2	(From D. L. Serventy)
†11. iv. 45	Swan River (W.A.)	24	(From D. L. Serventy)
†27. viii. 45	Wilson's Inlet (W.A.)	8	(From D. L. Serventy)
6. ix. 45	Two People Bay (W.A.)	1	(From D. L. Serventy)
28. iv. 47	Coffin Bay (S.A.).	135	Lampara
1. v. 47	Off Sceales B. (S.A.)	2	*Ex* barracouta
23. iv. 48	Swan River (W.A.)	13	(From G. W. Rayner)
	Total	343	

Samples indicated † in the first column are those from which some scales were available.

INVESTIGATIONS ON UNDERWATER FOULING

I. THE ROLE OF BACTERIA IN THE EARLY STAGES OF FOULING

By E. J. Ferguson Wood*

[*Manuscript received March* 3, 1949]

Summary

Investigations of the biological factors involved in the fouling, by organisms, of objects immersed in sea-water have been commenced. It has been shown that algal spores, diatoms, and to a smaller extent, bacteria are concerned in initiating primary organic film formation on glass slides immersed in the sea at stations on the coast of New South Wales near Sydney.

I. Introduction

During the war against Japan considerable difficulty was experienced by our armed services owing to the rapid fouling of vessels, both large and small, in the tropical waters in which they were engaged. A committee—Inter-Services Committee No. 6—was formed to attack this and other problems, and the Fisheries Division of C.S.I.R. was asked to carry out the biological section of the work. At the conclusion of hostilities the Committee disbanded, first recommending that the fouling and anti-fouling investigations be continued as a peace-time project.

As the Fisheries Division had a staff already engaged on fouling research and as fouling has a definite association with other parts of the Division's programme, it was logical that the biological work on fouling should continue at this laboratory.

The present paper is the first of a series which it is hoped to publish and which will deal with various aspects of the biology of fouling. Because of the interest in underwater fouling in other countries and because of the general scientific interest of much of the work, it is considered advisable to publish separately the results of each section of the work, rather than to give a full account of the whole research at the end of a long period.

The advantages of a biological approach to fouling as a means of assisting in anti-fouling measures have been recognized by Great Britain, where the Iron and Steel Corrosion Committee is doing work similar to that contained in our programme, and by the United States, where fouling biology is studied at Wood's Hole and at the Scripps Institution at La Jolla. This paper shows that one cannot take for granted the results of tests made in other countries, and that with the big coast-line of this continent, fouling studies are likely to produce very useful results.

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* Division of Fisheries, C.S.I.R.O.

It has been suggested by ZoBell (1939) and other authors, especially those working at Wood's Hole during the war, that, when slides or plates are immersed in seawater, a primary bacterial film is first formed. This, it is stated, consists of bacteria and organic detritus which are adsorbed on the surface, the detritus acting as food for the bacteria.

ZoBell states, "Bacteria are the first organisms which appear and within a few hours several hundred thousand bacteria are found per square inch of glass so tenaciously attached that they resist dislodgment in running water. Differential staining procedures supplemented by microchemical analyses show that the attachment of bacteria is accompanied by the accumulation of organic matter both particulate and dissolved. Although seawater normally contains less than 10 mg. of organic matter per litre, enough is adsorbed by glass slides to give a positive test. The attached bacteria commence to multiply at the expense of the organic matter and micro-colonies become evident within a few days. In the meantime, other bacteria are attaching and more organic matter is accumulating.

"Once this primary film has begun to form it serves to enmesh and hold additional amounts of detritus as well as both living and dead micro-organisms. Then in rapid succession there appear increasing numbers of diatoms (microscopic plants), and the larvæ of various sedentary or sessile forms such as barnacles, bryozoa, worms, and others."

The number of organisms per square centimetre on submerged slides at La Jolla, California, in June is given by ZoBell (1939) as follows:

Type of organism	Period of submergence		
	24 hours	48 hours	96 hours
Bacteria	278,000	1,962,900	11,570,000
Diatoms	138	555	1,200
Protozoa	11	43	163
Barnacle larvae	0.014	0.042	0.17
Others	57.6	200	1,552

Unfortunately much of the work done on the subject of primary film formation in the United States was confidential and has not yet been published, but it appears from the information available to the author that considerable importance is attached to the bacterial film by the workers on the eastern seaboard of the United States. One worker, however, found that few bacteria attached for a period of 12 hours to 5 days, depending on conditions.

II. Experimental

In the current investigations at this laboratory the adherence of organisms has been studied, where possible, on plates immersed in the sea for 7 and 14 days as well as for longer periods. From the weekly plates it seemed doubtful if bacteria were as important in these waters as they appear to be overseas. A series of experiments was therefore devised to study the question.

The first series of tests consisted of the exposure of clear glass slides held vertically at a depth of approximately 18 in. below low spring tide level. The slides measured 3¼ in. x 4¼ in., the centre square inch being the portion examined in each case. The slides were exposed for periods of one hour to nine days. Exposures were made at the following places:

(1) *Cronulla laboratory jetty.*—This jetty ends in the boat channel at Port Hacking, where the waters are, except after heavy rain, marine rather than estuarine and where there is a heavy growth of *Ecklonia* and *Hormosira.*

(2) *South West Arm, Port Hacking.*—This is about five miles upstream from Cronulla in a reach of water closed off from the Port excepting at high tide. A small creek runs into the head of the reach. The waters are hydrologically marine and very stable. Ecologically they are estuarine.

(3) *Shell Point.*—This is a shallow bay about eight miles from the sea, and is part of George's River. The hydrological environment is estuarine with a marine salinity, while ecologically *Zostera* is the predominant plant. Oysters are grown in the area.

(4) *The Spit, Middle Harbour, Port Jackson.*—This was a testing station for anti-fouling paints during the war, and usually shows heavy fouling. It is hydrologically marine. The slides used were carried in copper-framed racks with plastic slide holders. It was found that the concentration of copper at the surface of the slide did not affect growth of organisms. Before use, each slide was washed in chromic acid, and then in tap water. After removal from the sea, the slides were dried, stained with safranin or by Gram's method (Hucker's modification) and examined using 5 x oculars and 1/6 in. and 1/12 in. objectives, the former for counting diatoms, algal spores, etc., the latter for bacteria. Table 1 shows the results of these tests.

It will be seen that in no case is there a continuous bacterial film over the slide and only after nine days were the bacteria in each field too numerous to count. In order to comply with statistical requirements (Hanks and James 1940), 20 fields were counted on each slide, working from the centre along two diagonals.

Clumping of bacteria round but not actually touching algal spores and detrital material was usual so that it would appear that the attachment of the bacteria followed that of the other material. Micro-colonies were rare.

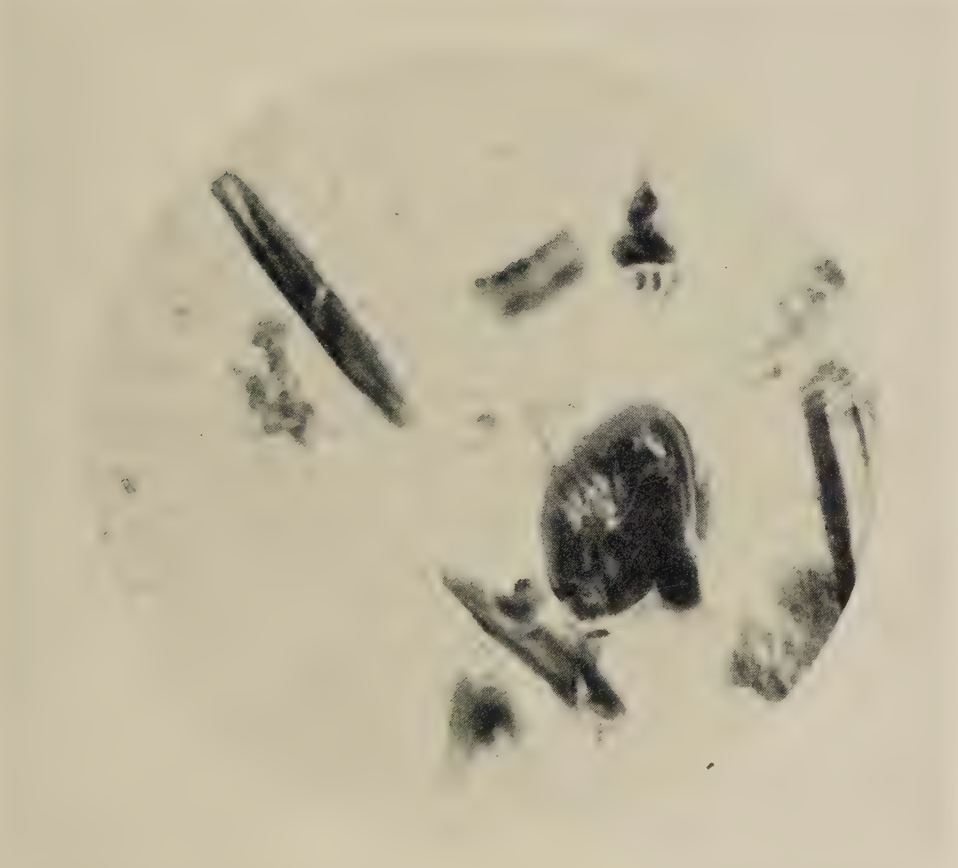
Diatoms did not attach to bacterial clumps when these were present, but were usually in direct contact with the glass or with larger particles of detritus. In the latter case, the appearance frequently suggested that the diatoms were attached to the detritus before it stuck to the slide. The earliest diatoms to attach were usually *Navicula, Nitzschia,* and *Thalassiothrix,* though *Licmophora, Striatella, Amphiprora, Amphora, Surirella, Nav. seriata, Gyrosigma,* and at times *Coscinodiscus* attached within three days. Algal spores attached within a few hours and after three days there was usually some development of algal spores into 5- to 20-celled stages and, after about five days filaments were numerous. On occasions, ciliates, flagellates, and a minute *Vorticella*-like form were seen. *Watersipora* appeared to attach directly to the slide irrespective of the distribution of bacteria, but did not attach, even when free-swimming forms were present in the water, until the slides had been immersed for five days. This form seems to require the presence of primary film, but not necessarily of bacteria, for attachment.

The second series of tests consisted of placing glass slides in a mixed bacterial culture composed of three motile, Gram-negative, pleomorphic rods (*Mycoplana*), which had been isolated from slides which had been exposed during a previous series of tests, and which had been shown to adhere to glass slides, and to remain attached after the slides had been washed with sterile salt water. The test slides were placed in the bacterial cultures for three days and all but one treated so as to kill the bacteria or to remove growth factors and enzymes. Two control slides were used. These had been washed in strong chromic acid to remove all organic material. The exposed slides were labelled as follows:

(*a*) No further treatment, i.e., live bacteria on slide.
(*b*) Heated to 85°C. for 10 minutes, i.e., only spore formers (if any) still alive on slide.
(*c*) Dipped in mercuric chloride (saturated solution) for 10 minutes to kill bacteria, leaving bodies on slide.
(*d*) Placed in alcohol-acetone for 10 minutes to remove enzymes and growth factors.
(*e*) Two control slides washed in chromic acid.

The slides were then immersed in the sea at Cronulla jetty for 14 days, dried at 85°C. for 10 minutes, weighed, scraped clean with a safety razor blade, scrubbed with a nail brush, and again weighed. It was found by examination that this method removed all growth except for a few bacteria (about 2 per field) and did not affect the weight of the slide within 0.001 g.

The weights of the material which had attached during the 14 days' exposure were:



24-hour fouled glass plate showing preponderance of diatoms over bacteria.
Stain—Gram.

TABLE 1

BACTERIAL COUNTS FROM GLASS SLIDES

Date	Exposure	Organisms	Count per sq. cm.			
			Cronulla	South West Arm	Shell Point	The Spit
9. iv. 47	1 hour	Bacteria	1,530			
		Diatoms	0			
		Algal spores	0			
27. v. 47	2 hours	Bacteria	3,060			
		Diatoms	0			
		Algal spores	830			
19. vi. 47	4 hours	Bacteria	1,683			
		Diatoms	30			
		Algal spores	Very numerous			
19. vi. 47	1 hour	Bacteria	612			
		Diatoms (*Licmophora*)	3,000			
		Algal spores	41			
30. vi. 47	1 day	Bacteria	1,300			
		Algal spores	500			
		Flagellates (not attached)	Numerous			
2. vii. 47	2 days	Bacteria	3,980			
		Diatoms	0			
		Algal spores	3,570			
3. vii. 47	3 days	Bacteria	3,060			
		Diatoms (*Licmophora*)	Numerous			
		Algal spores	12,450			
4. vii. 47	4 days	Bacteria	12,700			
		Diatoms (4 genera)	Numerous			
		Algal spores	2,520			
5. vii. 47	5 days	Bacteria	198,900			
		Diatoms (5 genera)	Very numerous			
		Algal spores	77,190			
9. vii. 47	9 days	Bacteria	Too many to count (No film)			
		Diatoms	Very numerous			
		Algal spores	28,400 (developing)			
9. xii. 47	5 days	Bacteria	68,850		76,500	7,650
		Diatoms	0		Numerous	410
		Algal spores	12,450		12,450	8,300
11. xii. 47	6 days	Bacteria	612,000			
		Diatoms (mixed)	4,150			
		Algal spores (and Algae)	Very numerous			
2. ii. 48	3 days	Bacteria				17,595
		Diatoms				125
		Algal spores				125
26. ii. 48	3 days	Bacteria		7,040	4,962	76,500
		Diatoms		0	500	2,570
		Algal spores		125	41	166
1. iii. 48	3 days	Bacteria				4,590
		Diatoms				0
		Algal spores				830
4. iii. 48	2 days	Bacteria			1,530	
		Diatoms			1,100	
		Algal spores			830	
8. iii. 48	3 days	Bacteria		14,076	1,530	
		Diatoms		3,240	41	
		Algal spores		2,075	830	
17. iii. 48	3 days	Bacteria				281,520
		Diatoms				830
		Algal spores				5,000
30. iii. 48	2 days	Bacteria	98,379			
		Diatoms	830			
		Algal spores	182,600 (Germinating)			
8. iv. 48	3 days	Bacteria		22,644		80,631
		Diatoms		1,100		1,800
		Algal spores		Few		46,900

(*a*) 0.110 g. (*b*) 0.065 g. (*c*) 0.100 g. (*d*) 0.160 g. (*e*) 0.110 g. and 0.110 g.

There appeared to be no increase in weight of subsequent growth owing to the presence of bacterial film alive or dead, as suggested by the Wood's Hole workers (private communication).

In the third series of tests, ground glass slides were used because these were standard at this laboratory for other work and because clear glass allowed the complete removal of growth by the methods used for cleaning the slides. The disadvantage was that they gave no means of counting the numbers of bacteria. The object of the experiment was to ascertain the effect of a previous immersion of slides in sea-water on the subsequent growth. The slides were accordingly exposed in sea-water off Cronulla jetty for 14 days, dried at 85°C. for 5 to 10 minutes and again exposed after the following treatments; a new dry plate was used as a control.

(*a*) New dry plate (control).
(*b*) Previously exposed plate after immersion in strong chromic acid for 15 minutes, no growth remaining.
(*c*) Previously exposed plate scraped clean with a safety razor blade, and oven-dried for 5 minutes at 85°C.
(*d*) Previously exposed plate dipped for 5 minutes in mercuric chloride solution (saturated).
(*e*) Previously exposed plate scraped wet with a safety razor blade.
(*f*) Previously exposed plate scraped and autoclaved for 15 minutes at 15 lb. pressure.

Treatments (*c*) to (*f*) left growth recognizable when viewed under a low-powered microscope. Treatment (*b*) was included to compare cleaned and new plates, treatment (*f*) in case some residual mercury might have proved toxic to further growth. In treatment (*c*) it was found that no growth of algae or bacteria could be detected after placing the plates in aged sea-water for 14 days. Bacteria were estimated by plate counts on the aged sea-water.

TABLE 2

WEIGHT OF GROWTH IN TESTS ON GLASS SLIDES

Test	Treatment					
	a	*b*	*c*	*d*	*e*	*f*
1	0.335	0.375	0.365	0.350	—	0.295
2	0.615	0.675	0.650	0.580	0.825	0.655
3	0.440	0.490	0.465	0.445	0.410	0.385
4	0.500	0.365	0.450	0.420	0.800	0.445
5	0.460	0.420	0.510	0.485	0.440	—
6	0.530	0.530	0.695	0.580	0.775	0.530
Mean	0.480	0.476	0.523	0.477	0.618	0.452

The results of six tests made at intervals of two months throughout a year are given in Table 2.

The results were analysed by Miss Helen Turner, Statistician to the McMaster Laboratory, Sydney, who reported that only treatment (*e*) showed a difference which could be regarded as statistically significant.

III. Discussion

The results suggest that live primary film promoted secondary growth, either by further growth of existing organisms plus new attachments, or by a stimulation of attachment and early growth of other organisms by providing food material or growth factors. The primary film in all these experiments was made up largely of algal spores, diatoms, and amorphous organic material, each of which in bulk was far greater than that of the bacteria. After scraping, the main residuum consisted of algal holdfasts and encrusting forms such as *Melobesia.* The algal spores were identified by watching their development on plates examined daily for seven to nine days, and their identification was confirmed by Dr. Tore Levring. The commonest forms included *Hormosira, Ectocarpus, Enteromorpha,* and *Chaetomorpha.*

It is concluded from these experiments that bacteria do not play as important a part in the formation of primary film as they appear to do in the United States, but that their place is taken by algal spores, while diatoms too are of some importance.

IV. Acknowledgments

Thanks are due to Miss Helen Turner, for statistical assistance, to Dr. Tore Levring for confirmation of the identification of the algae, and to Dr. H. Thompson and Dr. A. Nicholls for helpful criticism of the manuscript of this paper.

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INVESTIGATIONS ON UNDERWATER FOULING

II. THE BIOLOGY OF FOULING IN AUSTRALIA: RESULTS OF A YEAR'S RESEARCH

By F. E. ALLEN* and E. J. FERGUSON WOOD.*

[*Manuscript received March* 3, 1949]

Summary

The results of the first year of work on a continuing investigation on the fouling of submerged surfaces are outlined, with some preliminary conclusions to be drawn therefrom. The work represents a study of glass plates exposed to fouling by marine growth in the south-east of Australia. Only the more abundant fouling organisms are listed and their seasonal abundance is shown.

I. INTRODUCTION

The first of this series of papers outlined the necessity for an intensive anti-fouling research programme in Australian and adjacent waters, and the events leading up to the initiation of such a programme.

The desiderata of a project of this nature are now so well known that there is no need for repetition. It is sufficient to state that any anti-fouling programme must have for its foundation a thorough knowledge of the organisms, including their life histories, season of attachment and rates of growth, together with the effect of toxic substances on them at various stages of their life cycle. It was to obtain this information that the Division of Fisheries, C.S.I.R., commenced its programme in March, 1946.

Ten field stations have been established on the east Australian coast between Eden, New South Wales, and Moreton Bay, South Queensland, where non-toxic surfaces are exposed at regular intervals. Most of the activity during 1946 was confined to the location of stations, perfection of technique, and the identification of organisms occurring on the plates. Some of the results obtained during 1947 are here presented.

II. APPARATUS AND METHODS

The non-toxic surfaces used in these investigations are rectangular ground-glass plates 100 x 85 mm. Plates are exposed for the required period in frames suspended to a depth of one to two feet below the lowest tide level.

The type of frame now in use consists of four three-eighths inch rods

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* Division of Fisheries, C.S.I.R.O.

screwed to square end-plates. Plate guides of riveted perspex fit over the rods, and are spaced according to requirements with tubing. The guides grip the longer sides of the plates, leaving a total effective area of 120 sq. cm. for exposure (Plate 1).

After exposure, the plates with the growth intact are examined microscopically under low and medium powers. The microscopic organisms, such as diatoms and Protozoa, are listed and counted. The plates, after draining off excess water, are oven-dried to constant weight. It is not possible to standardize the drying time of plates even of the same length of exposure. For example, a plate on which the growth is predominantly algal retains water longer than one covered with encrusting bryozoa, and so prolongs the drying time.

Macroscopic organisms are counted, measured, and if in sufficient quantity, weighed. Finally, any remaining growth is removed with a safety razor blade, and the plate is scrubbed with a nail-brush in running vater. If necessary, plates are passed through a weak solution of hydrohloric acid to remove calcareous fragments. When thoroughly clean, plates re again dried and weighed, the difference between the two weights giving he approximate weight of growth in the dry state.

III. EXPOSURE OF PLATES

The shortest regular period of exposure at each station has been overned entirely by the distance of that station from the Laboratory. n exposure of twenty-eight days was adopted initially, as this was in ccordance with overseas practice, and at the same time, the minimum hat could be made in most of the localities on the New South Wales coast. his length of immersion proved so satisfactory that it was retained, and he results from these plates form the basis of this report. Plates are lso immersed at all stations for three- and six-monthly periods, for the tudy of succession and rates of growth.

In addition to the foregoing, exposures of 7 and 14 days are made at ronulla and Shell Point, and of 14 days at South West Arm, Port acking. These short-term plates, which are most useful in the study f primary foulers, particularly diatoms, have been exposed regularly nce the inception of the programme.

After exposure, plates are transported to the Laboratory immersed sea-water; to which formalin is added if necessary. For this purpose, a pecial water-tight carrier was devised.

IV. THE STATIONS

Cronulla.—Situated at the entrance to Port Hacking, about half a mile from the open sea, the Laboratory jetty is the present site for this tation. The frames are suspended over a sloping rock shelf, on which s a heavy growth of *Ecklonia*, *Hormosira*, and other algae, in addition o the common ascidian *Pyura stolonifera* (?).

As would be expected, algae predominate on plates from this locality. Attaching commonly throughout the year are species of *Ectocarpus*, *Enteromorpha*, and *Melobesia*. Diatoms and the bryozoan *Watersipora cucullata* also occur abundantly.

The annual temperature range is from about 14.2°C. to 23.1°C., but during 1947 a minimum of 12°C. and a maximum of 26.1°C. were recorded. Salinity remained fairly constant at about 35.25 per cent.

South West Arm.—This station is situated two and a half miles up Port Hacking from Cronulla. This arm of Port Hacking, particularly in the vicinity of the station, is very deep, but the entrance is closed off by a sandbank on which there is usually less than two feet of water at low tide. The growth on plates is very light in comparison with that occurring at other stations. Small algae, diatoms, and cyclostomatous bryozoa occurred on almost every plate.

During 1947, recorded temperatures ranged from 13.0°C. to 26.4°C., and salinity from 32.0 to 35.86 per cent.

Shell Point.—Shell Point is about six miles from the sea, situated in a backwater at the mouth of the Georges River, which in turn empties into Botany Bay. The cultivation of oysters is carried out on the mud-flats in the immediate vicinity.

The frame is suspended in shallow water at the end of the jetty. The growth on the plates is identical with that on the piles. A distinct decrease in the quantity of growth has occurred during 1947, as compared with 1946.

Minimum and maximum temperatures were 12°C. and 26°C. respectively, while the salinity varied from about 34.2 to 36.0 per cent.

North Head.—This station is one of two in Port Jackson, and corresponds to Eden, Jervis Bay, Cronulla, and Port Stephens insofar as it was located as close to the ocean as conditions would permit. It is at the Quarantine Station less than one mile inside the entrance to Sydney Harbour.

Nearby wharf-piles are heavily fouled, the most obvious organisms being *Ecklonia*, *Mytilus*, and *Pyura*. No hydrological data are available.

The Spit.—The Spit is about two miles from the Heads, in Middle Harbour, an arm of Port Jackson. Located in relatively unpolluted waters, this station records a heavy growth which is rarely exceeded in any other part of the Harbour. *Mytilus*, *Eupomatus*, and *Balanus* attach abundantly, while bryozoa, tunicates, and hydrozoa occur commonly. No recent hydrological data are available.

Port Stephens.—One hundred miles north of Sydney is the large harbour of Port Stephens. The station is just inside the entrance on the southern side, in Nelsons Bay. Harbour installations are heavily fouled, mostly with *Pyura*. The growth on plates has been variable, but in the main fairly heavy, with *Balanus*, bryozoa, and hydrozoa predominating.

During 1947, temperatures ranged from 14.50°C. to 23.90°C, and alinity from 34.0 to 35.71 per cent.

Moreton Bay.—It was originally proposed to establish three stations n this area. They were to be spaced out along the main shipping channel rom the mouth of the Brisbane River, to either Combyuro or Cowan Cowan. The first was at Bulwer Island, at the mouth of the Brisbane, and he second at Pile Light. It was impracticable to place the third station n either of the localities selected, so Dunwich, on Stradbroke Island, was hosen.

Because of its very exposed position, much gear was lost from Pile Light and this station was abandoned. No results are given here from his area. Due to the distance from the Laboratory (over 500 miles) t has not been possible to collect plates at less than three-monthly intervals and the resulting data are considered insufficient for publication. It is oped that permanent monthly stations may be established in Moreton Bay when the Division's branch Marine Biological Laboratory is established t Dunwich.

V. The Attachment of Organisms

Mention has been made of the exposure of weekly and fortnightly lates at three Sydney stations and their value in the study of primary oulers. During all months of the year, excepting the coldest (July and August), plates immersed for seven days show at the end of that period discernible amount of growth. It has been shown by one of the authors Wood) that bacteria do not appear to play such an important role in rimary film formation in this area as they do overseas. Certainly a rimary film does occur, but diatoms largely replace bacteria in its ormation, at least in the areas investigated.

Diatoms and algal spores attach very soon after the plate is immersed. At the end of a week there is usually a large and varied diatom population, many young *Ectocarpus* and *Enteromorpha*, and frequently a few red lgae of the genera *Polysiphonia* and *Ceramium*. Usually *Vorticella* is lso well established, and the bryozoan *Watersipora cucullata* is rarely bsent.

Fortnightly plates show a similar picture, but the organisms have increased considerably in size and number. By this time, juvenile Serpulids and barnacles have appeared, but large counts are exceptional. Attached oo are well-developed colonies of compound ascidians and bryozoa of a number of species.

The appearance of a plate at the end of four weeks is frequently in marked contrast with one exposed for half the period. Usually much of he algal material has disappeared, and the diatom population is often educed. Predominant are barnacles, which frequently reach 8 mm. in iameter, serpulids, and bryozoa. Also occurring are hydroids, juvenile ascidians, mussels, and oysters.

It is generally at this stage that the greatest number of species are present. Further immersion results in the elimination of many of these, however, particularly in the period from three to six months after setting.

VI. DIATOMS

The study of Australian marine diatoms, especially the sedentary forms, has been very much neglected. This, coupled with the impossibility of obtaining the older literature on the group, renders identification of the many species difficult. As a consequence, only a comparatively small number (forty-five) is listed as occurring on the plates, Most frequent on the plates are representatives of the genera *Berkeleya, Licmophora, Micromega, Nitzschia, Schizonema, Striatella,* and *Synedra.*

The diatoms undoubtedly need to be investigated thoroughly. In this regard the authors can add little to the observations of Coe and Allen (1937), as our findings coincide with theirs. They stated (p. 121): "The diatoms require special attention in connection with this report, not only because they have constituted a large part of the growths on every one of the experimental plates and blocks, but also because most of the animal life here recorded would not have been possible without the diatoms as food."

No information is given here on the attachment of these organisms. They are now receiving special attention, and will be the subject of a report to be published in due course.

VII. ALGAE

Few species have been identified specifically. This is due mostly to the occurrence on short-term plates of young plants, which do not exhibit sufficient adult characteristics for accurate determination. On plates exposed for periods longer than four weeks, usually little if any algal material occurs.

The kelp, *Ecklonia radiata* (Turn.) J.Agardh, has not attached to the plates, yet it is abundant on long-submerged wharf-piles and other structures on the sea-coast, and in the harbours where marine conditions prevail. However, young plants appeared on brass frames at Cronulla throughout September and October.

On the plates, species of *Ectocarpus* and *Enteromorpha* were the commonest forms met, while *Polysiphonia, Ceramium,* and *Colpomenia* were slightly less abundant. All these species attached throughout the year. They occurred commonly, even in profusion, at Cronulla in every month, but their presence at other stations was erratic. The species of *Cladophora, Dictyota, Laurencia, Melobesia,* and *Ulva* were sometimes common, but always fewer than the foregoing. Their occurrence has not been confined to a particular month or series of months at any of the stations. It may be mentioned that, in contrast to the heavy settlement at

Cronulla, there is a paucity of all algae on plates from Jervis Bay and North Head. A corresponding sparsity of diatoms also occurs.

VIII. PROTOZOA

The term Protozoa here includes only the ciliates *Epistylis, Vorticella, Zoothamnion,* and *Folliculina,* and the Suctoria represented on the plates by *Podophrya* and *Ephelota.* These are the only genera whose presence has been recorded. Of course, there was an abundance of free-swimming protozoans of every description on all plates, predominant among them being ciliates, flagellates, and foraminifera of many species.

There was only an isolated occurrence of *Epistylis,* this being at Shell Point during two weeks of October. It was absent throughout the year at other stations.

Vorticella is almost invariably present on the plates, though considerable fluctuation in numbers takes place. So far, these fluctuations do not appear to coincide with changes in hydrological conditions. Whilst this organism has attached in large numbers at Shell Point, an estuarine locality, it has been present as commonly at the near-oceanic stations. This suggests that, while *Vorticella* may usually prefer polluted waters, it can and does occur no less frequently in waters which may well be considered free from pollution.

To a lesser extent the same remarks apply to *Zoothamnion,* an allied form. The occurrence of members of this genus was much less regular than *Vorticella. Folliculina* attached to both the surface of the plate and to the other organisms present. Its occurrence has been most irregular, but when present it usually occurred in great numbers.

Of the Suctorians *Podophrya* and *Ephelota* little is known as yet. *Ephelota* has appeared at times in considerable quantities, but it too had peaks of abundance at widely separated intervals in different localities.

IX. PORIFERA

None of the species occurring has yet been positively identified. All belong to the Class Calcarea, and probably to the genera *Leucosolenia, Grantia,* and *Sycon.* So far none of the siliceous sponges have appeared on the plates. One or two species formed the largest part of the growth on long-term plates lifted in December from The Spit. Their occurrence, however, is mostly confined to the presence on monthly plates of *Sycon*-like juveniles up to 1 mm. in height.

X. HYDROZOA

The hydroids have been well represented on the plates. In size, the most important are the Athecate forms, such as *Bougainvillia ramosa, Eudendrium* sp., *Halocordyle disticha australis,* and *Tubularia australis.* Other than *Eudendrium,* they all occurred in abundance at The Spit in the period from March to June. Outside this period, *Halocordyle* was also present at The Spit in November and December, and *Tubularia* in November. A much smaller form, *Sarsia minima,* attached abundantly at North Head, also in the March-June period.

Of the more numerous Thecate forms, the most frequent has been a *Clytia,* which may be *C. serrulata* Bale. Quite often this species was present on weekly plates at Cronulla during summer and winter months, and at other stations sometimes covered the whole plate in four weeks. At present there is little basis for comparison of its attachment in the various localities. This is also true of the other common forms. *Obelia australis, Halecium mediterranium,* and *Opercularella lacerata* all present inconsistencies in their occurrence. Nevertheless they have been at times the predominant organism on plates from the near-oceanic localities. The last four species all settle at all stations from Eden to Port Stephens.

In the Moreton Bay area *Lytocarpus phillipinus* is the most outstanding species in frequency of occurrence, but has not settled at stations further south.

XI. Bryozoa

The Bryozoa have formed a large proportion of the growth on almost every plate. Of the many occurring (some thirty species), *Watersipora cucullata* is undoubtedly the commonest, and is almost certainly the most important species on the New South Wales coast. In many localities it can be found on jetties, etc., about low water mark, in masses several inches in thickness. Its tolerance to copper-based anti-fouling paints has been shown by Weiss (1947).

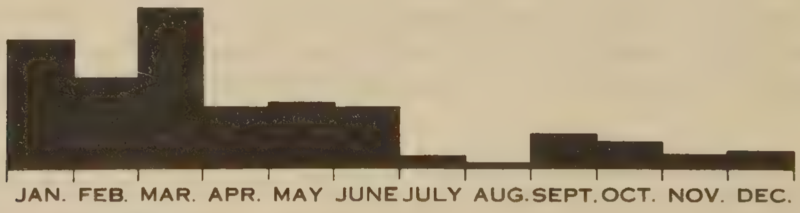


Fig. 1.—Occurrence of *Watersipora cucullata* at Cronulla for 1947.

Watersipora attached continuously during the whole twelve months under review (Fig. 1). Except for the period from June to August it was present as numerous (up to 30) single zooecia on weekly plates. In the winter months mentioned there was a notable decrease in the number of larvae settling, but they were rarely completely absent. At most stations the peak of abundance occurred from February to April, except at The Spit, where the peak was reached in June-July.

Conopeum reticulum is another encrusting form that is of some importance. It can be found on most submerged surfaces in the Sydney area. At Shell Point, The Spit, and North Head it attached in May, again in October at Shell Point, and in November-December at North Head.

Holoporella sp. is another very common fouler on this coast. During 1947 its only occurrence on monthly plates was at North Head in January, but it was usually present on the three and six-monthly plates at other stations. This form has been recorded as *Holoporella albirostris*, but it is certainly not that and appears to be an undescribed species.

Acanthodesia savartii, while occurring in the Sydney area, is far more abundant in northern waters. It is one of the most conspicuous foulers on buoys and jetties in Moreton Bay, and was also present on mines examined along Cape York Peninsula.

Three species of *Bugula* — *B. avicularia*, *B. flabellata*, and *B. neritina* — all occur commonly in season. *B. avicularia* prefers sheltered and estuarine waters. At South West Arm there was only a slight settlement during May. At Shell Point it was much more common, attaching in the summer months from November to March. In 1947, it was most abundant in November at Shell Point and The Spit. At the latter station it was also present in June and July.

The occurrence of *Bugula neritina*, which frequently formed a large proportion of the total growth, cannot be summarized so easily. It can be stated, however, that it was only during the three months, August to October, that it did not attach at one or more of the stations. It was commonest in January at both Shell Point and Cronulla, while the peaks were reached in November at The Spit, and December at South West Arm.

Bugula flabellata has occurred only at North Head, Port Stephens, and Jervis Bay. It seems, therefore, to prefer localities where hydrological conditions approximate to those of the open sea. This species settled on monthly plates at North Head in April, May, November, and December, and only in July at Port Stephens.

The other species recorded occur frequently, but to a lesser extent than those already mentioned. Their significance is probably not as great, but all contribute to the formation of the fouling community. Such forms as *Aetea truncata*, *Eucratea chelata*, and *Nolella alta*, because of physical characteristics, cannot assume overmuch importance from the fouling viewpoint. The encrusting species, however, need closer attention. Species of *Acanthodesia*, *Conopeum*, *Microporella*, *Watersipora*, etc., have completely covered a whole plate in a comparatively short time. In so doing they have created a surface which may be more favourable to the attachment of some of the larger organisms, such as tunicates. It is not unusual to find on heavily fouled long-term plates an underlying layer of an encrusting bryozoan. One such instance of this was seen in an exposure of six months made at Shell Point, from September 1946 to February 1947. Initially, this plate had been completely fouled with *Acanthodesia savartii*. At the end of six months it carried the heaviest attachment of ascidians recorded from this station, forming 95 per cent. of a total weight of 327 g. Although similar cases have come to notice, it is not suggested that the presence of a bryozoan is essential for the attachment of ascidians or any of the larger organisms. It may be that the bryozoans concerned have a fast rate of growth and that the circumstances leading to the example mentioned were purely coincidental.

XII. SERPULIDS

The number of species of polychaetes occurring on the plates is relatively small, but includes the five commonest serpulids of the New South Wales coast. They are *Galeolaria caespitosa, G. hystrix, Hydroides multispinosa, Salmacina australis,* and *Spirorbis* sp.

There is little doubt that *Hydroides multispinosa* is the most prolific serpulid fouler in this area. Attaching to any substratum, it grows very quickly, often reaching 25 mm. in four weeks. As many as sixty tubes on a plate of this length of exposure are commonly found. Although attaching during most months of the year, it was most abundant from about April to July.

The tubes of *Galeolaria caespitosa* are a very common sight in the lower intertidal zone on the foreshores of Sydney Harbour. In some localities, this species encrusts rocks, wharf-piles, and buoys to a depth of three or more inches. During 1947 it attached to the plates from January to June, and from October to December (Fig. 2). The peaks of abundance were from February to April at positive stations. It may be added that *G. caespitosa* does not appear to live much below low-water mark. From this level down to considerable depths it is replaced by an allied but very distinct species, *G. hystrix.* Whilst the latter is common on long-term plates, it was present on monthly plates only at Port Stephens, in March. Both species settled at all stations other than Shell Point.

XIII. MOLLUSCA

Mytilus obscuras is the south-eastern Australian representative of the mussels, which are prominent as fouling organisms in all temperate seas. In most ports along this coast *Mytilus obscuras* commonly and heavily fouls harbour installations. This can be seen to advantage in many parts of Port Jackson. From descriptions and photographs of mussel fouling in other parts of the world, it can be stated without hesitation that, in some areas at least, this or similar species produce an equally heavy attachment.

Ignoring the slight attachment to plates at Cronulla and South West Arm in March and December respectively, the most useful information obtained so far has been from The Spit and North Head. At the former *Mytilus* was present in April, and then in every month from June to December (Fig. 3). The period of greatest occurrence was from September to November, in which month this mussel reached the peak of its abundance. At North Head *Mytilus* did not attach so freely, occurring in May, July, and from September to December. Here, too, the maximum was reached in November.

Saxostrea commercialis is the common rock oyster, which is cultivated in New South Wales and southern Queensland. Although it is commonest in the lower intertidal zone, it has attached quite commonly to the plates. Again, The Spit and North Head stations supplied the only useable data. At the former station this species was present on plates from January to June, and in December. The months when it appeared in significant numbers were April and May, the peak occurring in the latter month. At North Head the attachment was much less, but still within the period as at The Spit. However, the peak was in February at North Head, three months earlier. *Saxostrea* also settled at the other stations.

Two other oysters, *Ostrea bresia* and *O. nomades*, are listed. Both these species are very common foulers in Queensland waters, and have attached commonly at Dunwich, Moreton Bay. To the best of our knowledge neither occurs in New South Wales. *Pinctada perviridis* is also a regular fouler at this station, but is rare at more southerly localities.

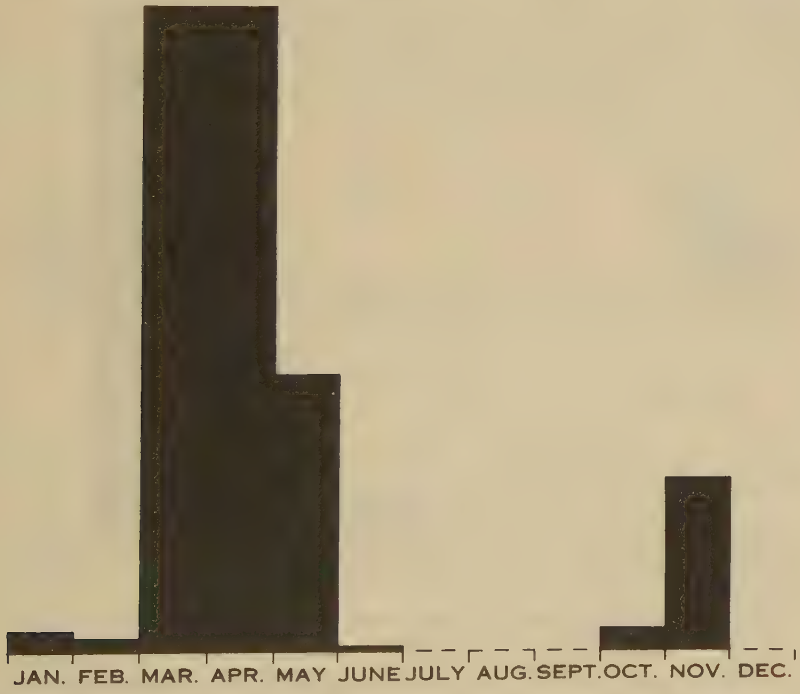


Fig. 2.—Occurrence of *Galeolaria* at North Head for 1947.

XIV. CIRRIPEDIA

In these waters three species of barnacles are responsible for most of the fouling below low-water mark. They are *Balanus trigonus* and *Balanus amphitrite*, varieties *cirratus* and *communis*.

Most frequent on the plates along the whole coastline, including Moreton Bay, is *B. amphitrite cirratus.* This variety attached in almost every month of the year, but its period of greatest abundance was throughout the summer months, from November to March (Fig. 4). During this period it is present in large numbers, a January plate from The Spit giving a count of over 3,000 juveniles up to 4 mm. in diameter. Certainly most of these were under 1 mm., but this figure gives some idea of the enormous number that would settle if large surfaces were available. Of course, only a small proportion of these would reach maturity. About this time of the year the rate of growth is greatest, occasionally reaching 9 mm. in four weeks at The Spit. More usually, however, a basal diameter of 5-6 mm. is the maximum reached in four weeks.

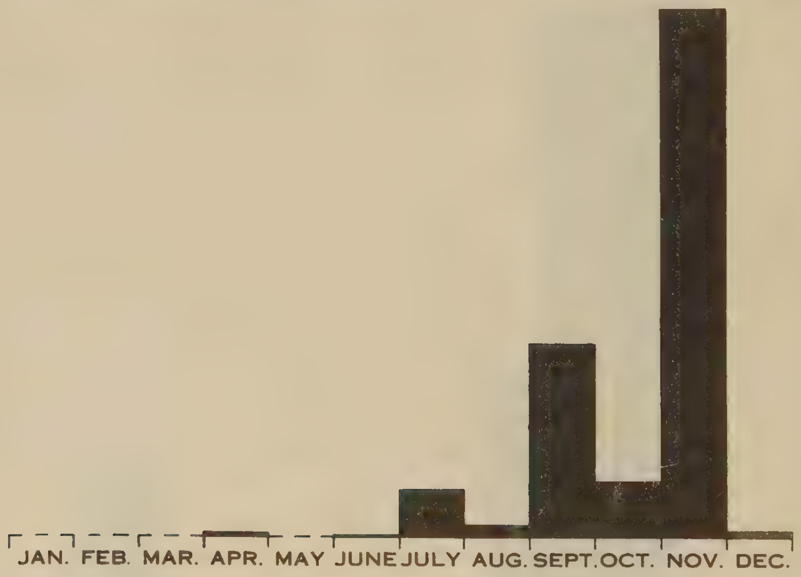


Fig. 3.—Occurrence of *Mytilus* at The Spit for 1947.

B. amphitrite communis has attached much less commonly. In fact, its appearance on the plates has been restricted to a few isolated settlements, mostly on long-term plates. It is probable that very young *communis,* up to about 3 mm., have been overlooked and included in the records with *B. amphitrite cirratus,* from which they would be difficult to separate at this size.

B. trigonus has attached at Eden, Cronulla, North Head, and Port Stephens, yet did not occur at The Spit, where otherwise the barnacle fouling is heavy. At the four stations mentioned, *B. amphitrite cirratus* also occurs, and some difficulty is experienced in differentiating between the two when the total attachment is of juveniles 3 mm. or less in diameter. Unless it was possible to establish their identity beyond all doubt, juveniles have been recorded as *Balanus* sp. At Eden, for instance, barnacles settled from January to May, and again in November. Because of their small size they were indeterminate, although it is tolerably certain that most were *Balanus trigonus*. Again, at Port Stephens, barnacles were present on every plate recovered, but only on three were any large enough to be determined with certainty as *B. trigonus*. This species has not at any time settled in considerable numbers.

Balanus (*Austrobalanus*) *imperator* has attached to other barnacles on long-term plates at North Head during summer months. As it is not a fouler the occurrence can be ignored.

XV. TUNICATES

Pyura stolonifera is the most prominent tunicate of the New South Wales coast, and in localities favourable to its attachment it heavily fouls harbour installations. It is mostly found in situations where there is a stable salinity approximating that of standard sea-water, a fairly high oxygen concentration, and some water movement (not necessarily wave-action). As a consequence, it reaches its maximum in size and numbers on the open sea coast where these conditions are fulfilled, but it does penetrate into harbours and estuaries. Usually *Pyura* attached only to long-term plates, mostly during summer months. An analysis of its occurrence and size on these plates indicates the season of attachment as being from about September to March or April. It has been found on plates from Eden to Dunwich, Moreton Bay.

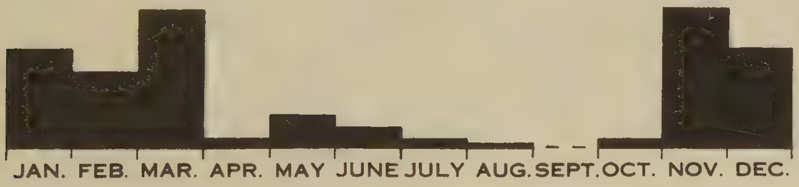


Fig. 4.—Occurrence of *Balanus* at North Head for 1947.

Styela plicata is typically an estuarine form, and has been most frequent at Shell Point. It attached also at Cronulla, The Spit, and North Head during 1947. The season of its occurrence is not yet clear, as, although commonest during the summer months from November to February, it occurred at Cronulla in May and August, and at Shell Point in May. In addition, some juveniles which may have been of this species attached at Eden, Cronulla, Shell Point, and North Head in the May-June period.

Another common form, especially at Shell Point, is *Microcosmus claudicans australis*. This species has, on present indications, two seasons of attachment. The first is in early summer (November-December), and

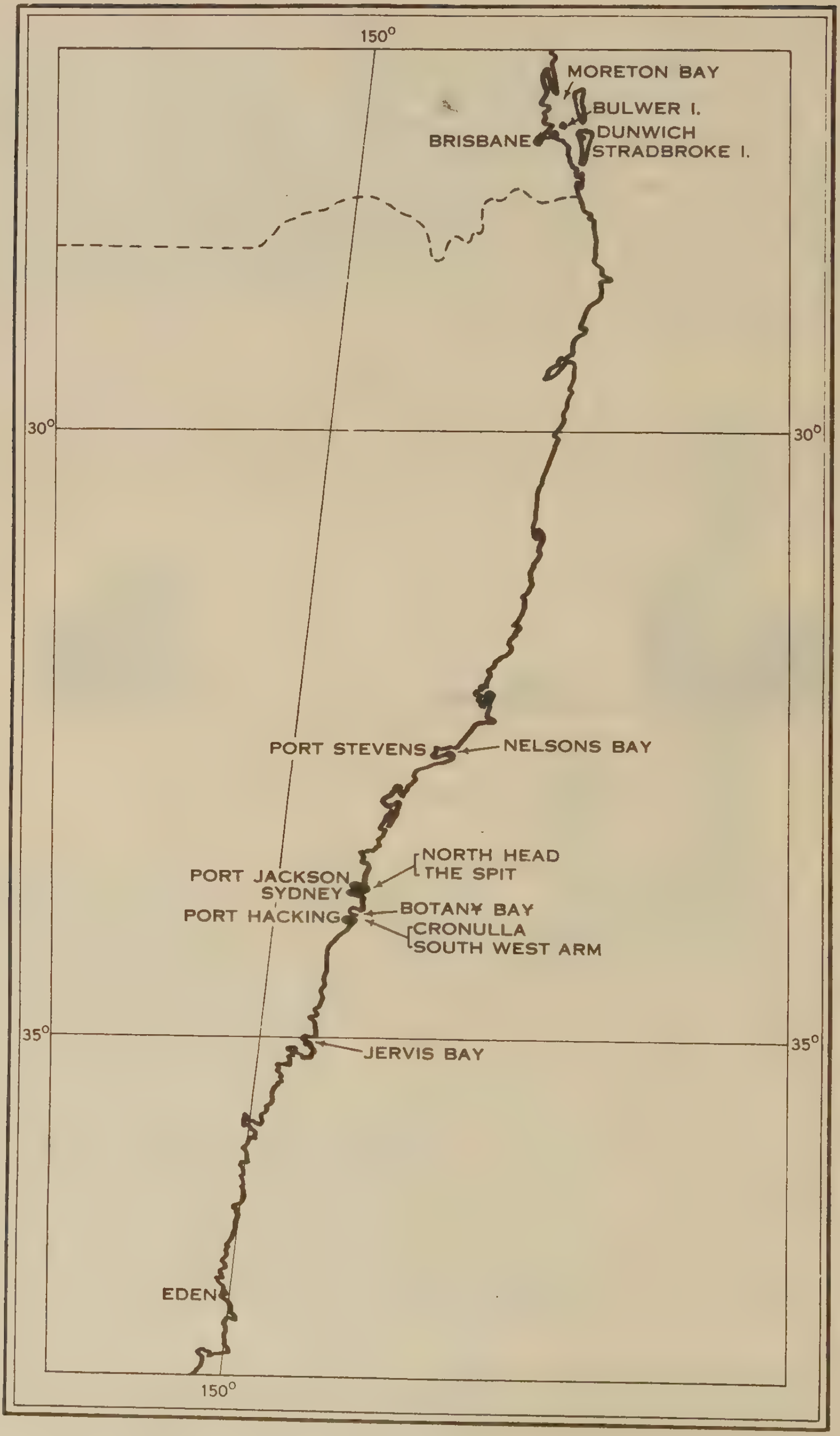
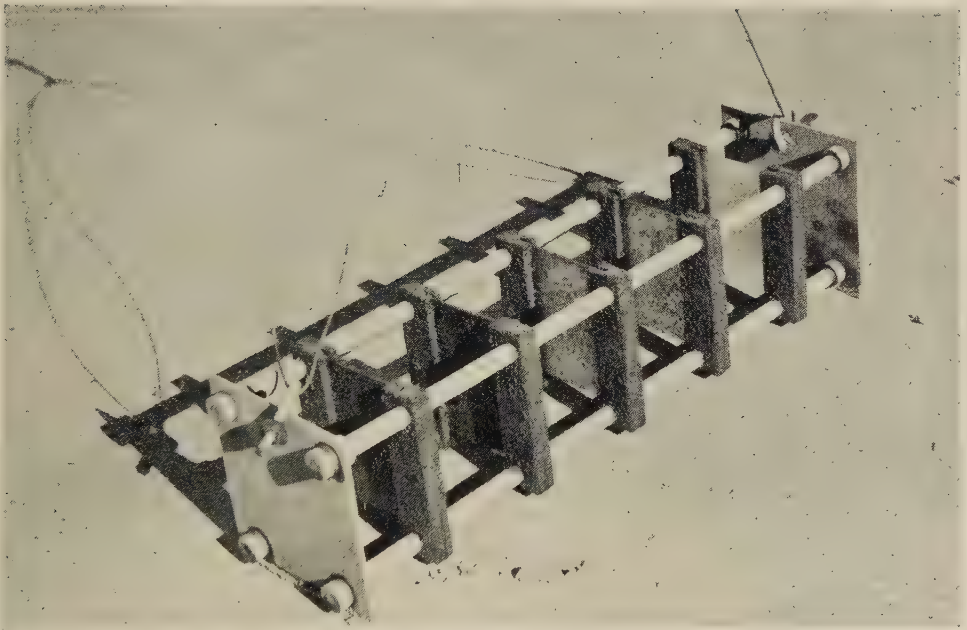
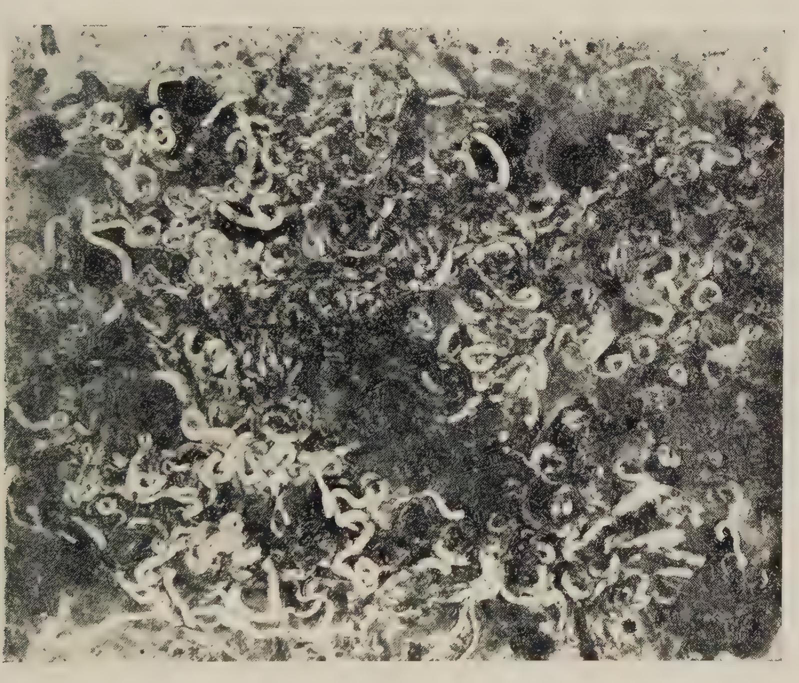

150°
MORETON BAY
BULWER I.
DUNWICH
BRISBANE
STRADBROKE I.
30°
30°
PORT STEVENS
NELSONS BAY
NORTH HEAD
THE SPIT
PORT JACKSON
SYDNEY
BOTANY BAY
PORT HACKING
CRONULLA
SOUTH WEST ARM
35°
JERVIS BAY
35°
EDEN
150°

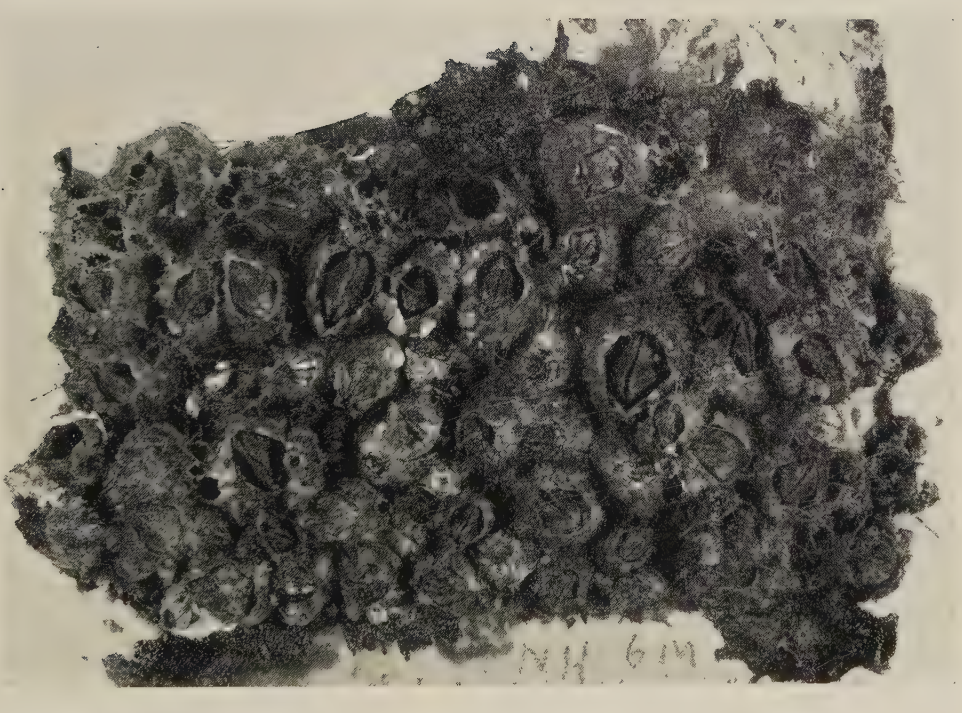
Fig. 5.—Map showing location of fouling stations.



Fouling frame at present used in this investigation.



Serpulid fouling, North Head, 3 months (April-June 1948).



Barnacle fouling, North Head, 6 months (June 1947-January 1948).

the second in April-May. So far, its settlement has been restricted to stations in the Sydney area, and Bulwer Island, in the Moreton Bay area.

Ciona intestinalis, a cosmopolitan species, occurs principally at The Spit. It attached here in April and from July to December. The peak was in November when thirteen were attached to a four weeks' plate, the largest being 10 x 7 x 3 mm. It has also settled rarely at North Head.

Distoma sp. is the most conspicuous of the compound tunicates in frequency of occurrence. Occasionally present on weekly plates, it has in four weeks sometimes covered three-quarters of the total area available. *Botrylloides* has also occurred, mostly at The Spit, but has been irregular in its attachment.

XVI. CONCLUSIONS

Although it is inadvisable to draw far-reaching conclusions from this preliminary work, some points are already fairly clear. The identity of the main fouling organisms in the waters of south-eastern Australia is now established. Some information on the relative importance of these organisms is already forthcoming. The occurrence of *Watersipora cucullata*, which hitherto had been recorded only from Torres Strait is noteworthy. The relative seasonal abundance of different foulers appears in the graphs (Figs. 1-4) and it will be noticed that different organisms have peaks of occurrence at different seasons of the year. This suggests that tests on antifouling paints made at different seasons will not be strictly comparable, as a paint exposed when, say, *Watersipora* is at a maximum will show a different type of cover from one exposed when, say, *Galeolaria* is predominant. Moreover, comparisons based on degree of cover, number of individuals or of colonies, or on weight will not give an assessment of the comparable value of the paints. (Plates 2 and 3.)

It is hoped that the present series of stations will be maintained for a period of years sufficiently long to allow of the recording of seasonal effects, alterations in the relative importance of organisms, and fluctuations. With the addition of projected stations further towards the north, the geographic range of various fouling species will be ascertainable. The present work must therefore be regarded as part of a pattern. However, since much interest in fouling problems now exists in various parts of the world, it is felt that publication of these preliminary results is justified.

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INVESTIGATIONS ON UNDERWATER FOULING

III. NOTE ON THE FOULING ORGANISMS ATTACHED TO NAVAL MINES IN NORTH QUEENSLAND WATERS

By F. E. ALLEN*

[*Manuscript received March 3, 1949*]

Summary

A study was made of organisms attached to six naval mines immersed for some years in north Queensland coastal waters. The most important groups represented were the mollusca, with ten species, corals, serpulids, bryozoa, and algae. By far the commonest organisms on all the mines examined were the molluscs *Chama* spp.

I. INTRODUCTION

The nature and extent of fouling of submerged surfaces in northern Queensland waters have been a matter of great interest for some time. As on much of the Australian coastline, the identities of organisms responsible for fouling were unknown. Interest in Queensland waters has been heightened by the results from the Moreton Bay stations (Allen and Wood), which, compared with New South Wales stations, show a change from one type of fouling to another. When the Royal Australian Navy in December 1947 gave the Division of Fisheries the opportunity to examine the growth on mines in north Queensland waters, it was readily accepted.

The mines were all Australian, laid in 1942 north of Cairns, and, judging by the marked similarity in growth, appeared to have been laid in the one field. For various reasons it became possible to examine only six.

On all mines, a varying proportion of the growth had been dislodged in beaching; in addition, exposure to wind and mid-summer sun had quickly dried out the soft parts of all organisms, leaving only the calcareous skeletons or shells. There were thus no traces of ascidians or hydroids, representatives of which could be expected to occur. The poor state of the growth and the absence of uncalcified tissues made identification of much of the growth rather difficult.

In the following discussion of each group and in the summary the mines are, for convenience, numbered from one to six, in the order of examination.

II. FOULING ORGANISMS

Algae.—Only one genus occurred with any certainty. This was *Lithothamnion*, represented by three small roughly circular patches, approximately 100 mm. in diameter, all on one mine (No. 5). The prominence of his genus in tropical waters, and its rôle in coral-reef building, are so well known that it was expected to occur very commonly on the mines. This single, almost negligible occurrence was therefore surprising.

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* Division of Fisheries, C.S.I.R.O.

Porifera.—A single specimen occurred on No. 4 and measured approximately 120 x 70 x 60 mm. Its very poor condition made it impossible to identify.

Madreporaria.—The largest organisms attached to the mines were the corals, which in importance were second only to the Mollusca. The smallest corallum to occur was 90 x 75 x 60 mm., whilst the largest slightly exceeded 250 x 250 x 150 mm. All belonged to the one genus, *Pocillopora,* and with several exceptions, all to the species *P. verrucosa* Ellis and Solander. Several small coralla, however, differed from the foregoing, and although not quite typical, closely resembled *P. bulbosa.* They did not occur frequently, or reach any great size, the largest being 135 x 110 x 70 mm.

It is worth recording that the largest and greatest number of corals occurred on or close to the cover-plate, which was uppermost when the mine was moored. Some few and smaller colonies were attached to the lower or under side, but probably 90 per cent. of attachment was to the upper half.

Pocillopora verrucosa occurred as follows:

(1) Nil.
(2) Six large coralla, largest 180 x 170 x 110 mm.
(3) Six large coralla, two largest 250 x 250 x 150 mm., others somewhat smaller.
(4) Five coralla, not as large as on No. 3.
(5) Ten large coralla, largest 200 x 190 x 120 mm., others slightly smaller.
(6) Five large coralla, largest 250 x 180 x 120 mm., others exceeding 180 x 130.

One other species, *Cylicea* sp., occurred, once, on No. 3. This small and often solitary form covered an area approximately 30 x 10 mm. in the groove beneath the cover-plate.

Bryozoa.—Acanthodesia savartii is an encrusting bryozoan common as a fouling organism in the Sydney area, and most abundant all over Moreton Bay. It was not surprising therefore to see it occurring very commonly on three of the six mines examined. On No. 3 especially, it completely encrusted all other organisms excepting corals. On No. 4 it was almost as common, but on No. 2 it occurred only in small irregular patches up to 110 mm. in major diameter.

The only other bryozoan observed was *Tubulipora pulcherrima.* It was found only in the groove beneath the cover-plate on two mines.

Somewhat unexpectedly *Watersipora cucullata* did not occur. This species is undoubtedly the most important encrusting fouling bryozoan on the eastern Australian coast. It has been recorded from Torres Straits, and occurs frequently in Moreton Bay, so that it is certain to occur in the localities between. This assumption was confirmed at Cairns. There, the M.V. "Leisha," which operates only in the Townsville-Cairns district, was on the slips, and on examination, the bottom was found to be well covered with *Watersipora*.

Serpulids.—Worm tubes of apparently one species occurred commonly. The absence of the animal and operculum made identification impossible, as the characters of the tubes alone are insufficient for determination. The tubes were white, sinuous, sub-trigonal, expanded at the base, rising steeply at the apex, with a prominent continuous crest. They appeared very much like the tubes of a New South Wales form, *Galeolaria hystrix* (better known as *G. rosea*), but lacked the characteristic rose colouring of that species. In addition, the average length of these tubes, 45 mm., was rather large for typical *G. hystrix*.

Mollusca.—This group is without doubt the most important fouling group in the area in which these mines were laid. It contributed at least 70 per cent. of total fouling on all mines, and was represented by ten species, four of which predominated. In order of importance they were *Chama divaricata, Ostrea quirites, Lopha cristagalli,* and *Chama broderipi.*

Chama divaricata was by far the commonest organism attached. On every mine it numerically exceeded all other species. Insufficient time forced the abandonment of counts, but series were selected for measurement. On No. 2, the average size was 70 x 50 mm., the largest being 70 x 53 mm. Average sizes on other mines were slightly less, whilst the largest measured reached 70 x 63 mm. *Chama broderipi* occurred commonly, but not in numbers approaching that of *C. divaricata.* This species was usually smaller, an average specimen measuring 50 x 40 mm.

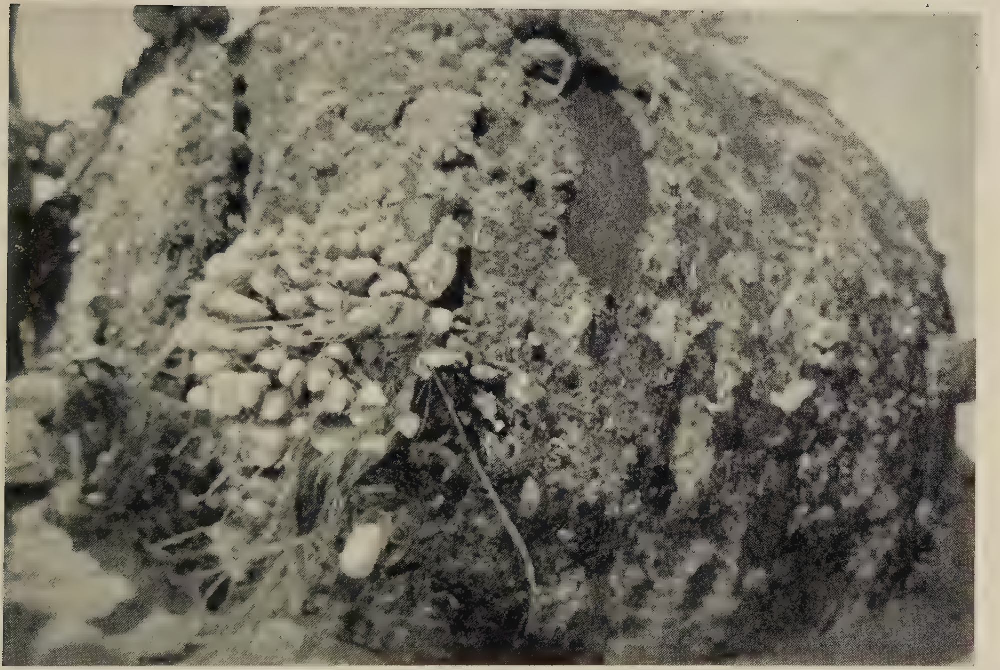
Ostrea quirites is a large, relatively thin-shelled oyster, occurring along the central and north Queensland coast. It occurred on five of the mines, and in many cases reached over 100 mm. in major diameter. Several of the largest measured 180 x 170 mm., but the majority were about 100 x 90. Although never equalling *Chama divaricata* in number, it was at times very common. At such times the shells were mostly small, usually about 60 x 50 mm. On others, the numbers were much less, but the size greatly increased.

Lopha cristagalli occurred frequently, but no very large specimens were seen. None exceeded 100 mm. in greatest diameter, and none was attached directly to the metal surface.

Spondylus sp. occurred moderately commonly on No. 2, but was rare on all others. The average of selected shells was 50 x 50 mm.

Numerous byssal threads indicated that *Pinctada* had been attached to all mines. Juveniles collected gave no clue to positive identification and no adults were seen, although they had been fairly common.

Adult *Musculus cumingianus*, *Septifer bilocularis*, and *Vermetus* sp.



One aspect of a mine (No. 5), showing the general state of the growth.
The large corallum is *Pocillopora verrucosa*.

were all attached, but were not very common on any occasion.

Cirripedia.—In view of the heavy barnacle fouling in temperate and sub-tropical waters, the almost complete absence of numbers of this group is of interest. The greatest numbers to occur were six or seven on No. 5, while two other mines had several each. Unfortunately, the identification of these could not be carried any further than *Balanus* sp. because of the absence of the opercular valves in every specimen. Basal diameter of the largest was 22 mm., while an average specimen was 20 mm.

TABLE 1

SUMMARY OF ATTACHMENT OF GROWTH ON MINES

Number	1	2	3	4	5	6
Place of Examination	S. of Cape Bedford	S. of Cape Bedford	Cape Flattery Beach	Cape Flattery Beach	Cape Flattery Beach	Cape Flattery Beach
Algae						
Lithothamnion					x	
Porifera				x		
Madreporaria						
Pocillopora verrucosa		xxx	xxx	xxx	xxxx	xxx
Pocillopora bulbosa		xx			x	
Cylicea sp.			x			
Bryozoa						
Acanthodesia savartii		x	xxxxx	xxxx		
Tubulipora pulcherrima			x	x		
Serpulids	xx	xxx	xxx	xxxx	xx	x
Mollusca						
Chama divaricata	xxx	xxxx	xxxxx	xxx	xxxxx	xxxx
Chama broderipi			xxx	x	xxx	
Lopha cristagalli	xx	x	x	xx	x	xx
Ostrea quirites	x		x	xxx	xx	xx
Septifer bilocularis			x		x	
Musculus cumingianus	x	x	x	x	x	x
Spondylus sp.		xx		x	x	
Pinctada sp.	x		xx		x	
Vermetus sp.	xx	xx				
Cirripedia						
Balanus			x	x	xx	

KEY.—Rare x, Moderately common xx, Common xxx, Very common xxxx, Abundant xxxxx.

THE CONDITION OF THE FISHERY FOR BARRACOUTA, *THYRSITES ATUN* (EUPHRASEN), IN AUSTRALIAN WATERS

By M. BLACKBURN*

[*Manuscript received July* 5, 1949.]

Summary

Barracouta is equal first with sea mullet in order of contribution by individual species to the Australian fish catch. The fishery is important only in Victoria and Tasmania, although the species is plentiful along the entire southern coast of Australia. From analysis of catch records, supported by observations on the fishery and the marketing situation, it is evident that there is no depletion. Variations in the catch reflect principally the demand for the fish, which is usually below the catching capacity of the fishermen. At present the catch is being maintained at twice the pre-war level by a demand for fish for canning, largely for export.

The influence of demand upon catch was remarkably shown in Tasmania during the war. There, in spite of opinions that the stocks were depleted, a four-fold increase in the annual catch was achieved, because of the demand and suitable control procedures. Barracouta was the only species in Australia which made a substantial contribution to the war-time demand for more fish.

I. INTRODUCTION

The barracouta, *Thyrsites atun* (Euphrasen), is a scombriform fish of the family Gempylidæ. It is found close to all lands in the cool subtropical (rarely sub-Antarctic) waters of the southern hemisphere, i.e., southern Australia, New Zealand, southern South America (including the Falklands), and the islands of Tristan da Cunha and St. Paul. It is called "snoek" in Africa, "sierra" in South America, and "barracouta" in New Zealand. There are significant fisheries in Africa, Australia, and New Zealand.

In southern Australian waters, the barracouta occurs from Moreton Bay to Fremantle. However, its range as a common species extends from the southernmost waters of New South Wales, through all Victorian, Tasmanian, and South Australian waters, to the neighbourhood of Albany in Western Australia. The fishery begins near Eden in the far south of New South Wales, and extends only through Victorian and Tasmanian waters, except those of the Tasmanian west coast (Fig. 1).

The barracouta is extremely important in the Australian fisheries. Table 1 shows the total recorded catch, for each of the years 1941-42 to 1946-47, of this and other species which have at times been first, second, or third in contribution to the total fish production of the Commonwealth. The catches of the trawl fishery as a whole, in which several species are

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represented, are also shown. These figures have been compiled from records published or otherwise made available by the fisheries authorities of Queensland, New South Wales, Victoria, Tasmania, South Australia, and Western Australia. It is impossible to present the information for earlier years in the same way, because of differences in recording procedure between the States. Indeed, Western Australian records are still only available on a calendar year basis, and such figures (for 1942-1947) have been used in compiling Table 1.

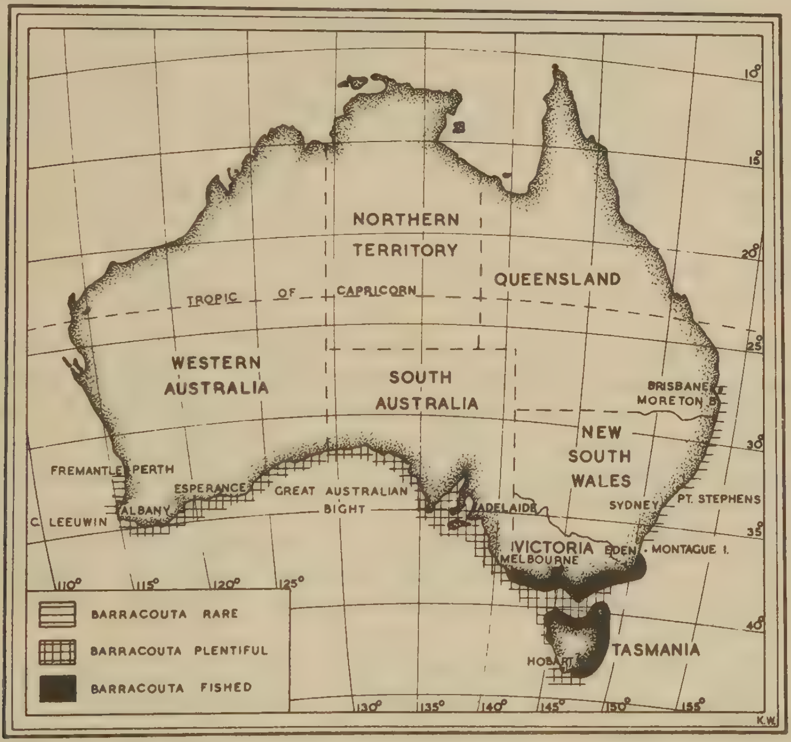

NORTHERN TERRITORY
QUEENSLAND
TROPIC OF CAPRICORN
WESTERN AUSTRALIA
SOUTH AUSTRALIA
NEW SOUTH WALES
BRISBANE
MORETON B.
FREMANTLE
PERTH
ESPERANCE
GREAT AUSTRALIAN BIGHT
ALBANY
C. LEEUWIN
ADELAIDE
SYDNEY
PT. STEPHENS
VICTORIA
MELBOURNE
EDEN
MONTAGUE I.
TASMANIA
HOBART
10°
15°
20°
25°
30°
35°
40°
110°
115°
120°
125°
130°
135°
140°
145°
150°
155°
BARRACOUTA RARE
BARRACOUTA PLENTIFUL
BARRACOUTA FISHED
K.W.

Fig. 1.—Australia, showing the approximate range of barracouta as a common and a rare species, and the general areas of the fishery.

As these figures stand, they show that sea mullet, usually the most important species, was temporarily overtaken by barracouta in 1944-45 and 1945-46. It was probably only in 1945-46 that the barracouta catch was actually higher, because the earlier mullet records are believed to be substantially incomplete. Australian salmon was the third species in importance in each year except 1941-42, when it was second. The figures given for that species are probably slightly incomplete. The tiger flathead figures are all much lower, but at an earlier period this species came second to sea mullet, barracouta being third. According to W. S. Fairbridge, of the C.S.I.R.O. Division of Fisheries, the mean annual catch of tiger flathead, for the four years 1937-38 to 1940-41, was about 6.0 million lb.; the figure for barracouta, for the four years 1937 to 1940, was 5.3 million lb. (See Table 2). However, although all the other fish in Table 1 are recorded in round or total weight, all barracouta catch figures are on a cleaned weight basis (head and viscera removed).

TABLE 1

RECORDED CATCHES OF SEA MULLET (*MUGIL DOBULA*), BARRACOUTA, AUSTRALIAN SALMON (*ARRIPIS TRUTTA*), TIGER FLATHEAD (*NEOPLATYCEPHALUS MACRODON*), AND ALL SPECIES (INCLUDING TIGER FLATHEAD) CAUGHT BY THE TRAWL FISHERY, FOR ALL AUSTRALIAN WATERS COMBINED, IN MILLIONS OF LB.

Year	Sea Mullet	Barracouta	Australian Salmon	Tiger Flathead	All Trawl Fish
1941-42	10.1	4.4	4.8	3.4	6.9
1942-43	10.3	5.4	5.0	0.5	2.2
1943-44	10.9	7.0	5.8	1.2	2.8
1944-45	8.9	10.2	5.5	4.7	10.1
1945-46	14.0	14.2	4.1	5.5	12.8
1946-47	15.0	10.5	6.1	4.9	16.2

The average ratio of cleaned to round weight is about 70 per cent. If the barracouta figures in Table 1 are accordingly raised by three-sevenths for comparison on a round weight basis, the 1946-47 catch becomes equal to that of sea mullet in the same year, with 15.0 million lb. The catch of all trawl fish was not much greater. As the barracouta catch has since risen (see Table 2), this species is probably still at least equal in importance with sea mullet in the total Australian catch, with Australian salmon third. It has long been the principal item in the Victorian catch. In Tasmania it temporarily yielded first place to crayfish (*Jasus lalandii*) (see Section III).

Biological research upon this species has only recently been revived in Australia. Previous investigations were interrupted by war and hampered by lack of workers and equipment. Little work has been reported overseas. However, a good deal of attention has been given in Australia to the circumstances of the fishery and marketing of the catch, combined with analysis of catch records.

II. THE FISHERY

An account of the fishery was published in the "Fisheries News-letter," Vol. 3, No. 5 (1944), by J. A. Tubb, of the C.S.I.R. Division of Fisheries. The following statement is partly a summary of that article, which is out of print.

Barracouta are caught on moving lures which carry one or two hooks. Victorian and New South Wales barracouta fishing practices are much the same and the lure used is a piece of red or white cloth, or a strip of rawhide, pork rind, or shark skin, lashed to the eye or shank of large hook. Occasionally two hooks are used, the barb of the leading ook passing through the eye of the second. The lure is attached to a race wire, from 3 to 6 ft. long, which is in turn fastened, sometimes with swivel, to a cotton line towed behind the boat. The line may be light, or use near the surface of the water, or weighted with lead to fish urther down. Sometimes salted anchovies are thrown over to attract

TABLE 2

ECORDED BARRACOUTA CATCHES (IN LB.) FOR THE SEPARATE STATES AND ALL COMBINED
TASMANIAN FIGURES APPROXIMATE ONLY (SEE TEXT)

Year	Victoria	Tasmania	New South Wales	All States
1911	2,377,685			
1912	2,656,351			
1913	2,748,697			
1914	2,485,877			
1915	2,845,438			
1916	3,738,277			
1917	2,532,566			
1918	3,115,365			
1919	2,965,486			
1920	3,549,498			
1921	3,974,757			
1922	2,905,149			
1923	1,879,189	2,947,012		4,826,201
1924	2,450,904			
1925	2,954,483			
1926	2,117,407			
1927	3,271,416			
1928	2,544,877			
1929	1,774,667	2,977,361		4,752,028
1930	4,217,609			
1931	5,056,510	1,360,250		6,416,760
1932	4,025,360	903,617		4,928,977
1933	4,461,425			
1934	4,517,869	1,693,670		6,211,539
1935	4,138,408	1,413,943		5,552,351
1936	4,079,884	1,498,982		5,578,866
1937	5,281,305	1,637,377		6,918,682
1938	5,487,941	1,888,357		7,376,298
1939	3,673,787	702,655		4,376,442
1940	2,439,852	277,769		2,717,621
1941	2,611,084			
1941-42	2,606,703	1,798,041		4,404,744
1942-43	2,919,352	2,444,911		5,364,263
1943-44	3,429,867	3,084,414	505,803	7,020,084
1944-45	3,552,823	5,803,932	881,281	10,238,038
1945-46	7,425,112	6,116,652	609,130	14,150,894
1946-47	5,855,949	4,568,070	118,712	10,542,731
1947-48	5,604,598	6,919,111	72,907	12,596,616

the fish. This method is also used in Tasmania, but most of the fishing there is done with the "jigstick." The lure in this case is a torpedo-shaped piece of wood about 6 in. long, to which two large barbless hooks are attached. The lure is fastened to a short chain of steel wire with links 4 to 6 in. long. This leads to the tip of a slender, flexible sapling about 8 to 10 ft. long, which is the jigstick itself. The tip of the stick is thrust into the water near the stern of the boat and kept rapidly moving there. When a barracouta seizes the lure it is swiftly swung inboard (Plate 1).

The fishery is carried on mainly with small sailing vessels, 20 to 45 ft. long, with auxiliary engines. When fishing they are usually under sail and rarely go faster than 4 knots. Crews may consist of one, two, or three men. Most of the fishing is done within five miles of land. Most barracouta boats fish only for that species in the season. They are based on a particular port, and make trips which are often of only a few hours' duration and which hardly ever last for more than two days. Two-day trips are common only in Tasmania, especially in the south. There the indented coastline sometimes permits comfortable anchoring near the fishing areas overnight, but such conditions do not usually apply elsewhere. Victorian boats are also much smaller, on average, than Tasmanian boats, and usually have no living quarters. Except for the few that have ice or refrigeration, the boats cannot remain out for more than two days unless the catch of the first day is thrown away.

At the end of a day's fishing the fish are headed and, in Victoria, fully cleaned and split. In Tasmania some fishermen do not split the fish, and only remove as much of the viscera as can quickly be pulled out of the end of the body cavity after the head is removed.

III. INTERPRETATION OF CATCH RECORDS

Figure 2 shows the total barracouta catch for Victoria, Tasmania, New South Wales, and all combined, for each year up to 1947-48, as far as the information is available. The most complete and reliable figures, which are given by weight, are those from the Victorian Fisheries Department. These are based on fishermen's catch returns from 1911 onwards (Table 2).

Similar data are available for New South Wales from 1943-44 (Table 2); previously the barracouta production in that State was negligible. The position for Tasmania is much less satisfactory. Whereas in the other States the units of catch are boxes of known average weight, in Tasmania the most common unit was until recently the dozen of fish, and the mean weight of this varies between areas, seasons, and years. The available data are:

(*a*) Records, in dozens, of fish passing through the Hobart and Launceston markets, and others exported from the State, in 1923 (from the published report of the Commissioner of Fisheries, 1922-23).

The total probably approximates to the complete State catch of the year.

b) Records of total State catch, in dozens, for 1929, 1931, 1932, 1934, and thence to 1940 (from published and unpublished reports of the Sea Fisheries Board). These were based on returns from dealers.

c) Total State catch for 1941-42 and 1942-43, established in terms of weight by J. A. Tubb and the author. In these years, fishermen were asked to make six-monthly returns, with catches listed by weight as well as dozens, to the Tasmanian Fisheries Division. This yielded enough information for calculating mean conversion factors for dozens, for different fishing areas in each half-year.

d) Total State catch for 1943-44. In this and later years returns were collected monthly, but the fishermen did not give details of weight corresponding to dozens. In dealing with the 1943-44 returns for each area, a conversion factor which was a weighted mean of those for the four previous half-years was used.

e) Total State catch for 1944-45 and subsequent years, established in terms of weight by converting all dozens at 44.5 lb. Over this period there was a great decline in the use of the dozen as a unit, and now about 95 per cent. of the catch is reported by weight.

The dozens data of (*a*) and (*b*) were also converted at 44.5 lb., noring the different areas. This procedure is not very satisfactory, but st errors are probably not serious when catch variations of the order millions of lb. are considered. Thus an approximate curve of annual smanian catch by weight can be plotted from 1929 onwards (see Fig. and Table 2). The 1923 figure was almost the same as that of 1929, d the general level of output is believed to have been similar in the tervening years.

Figure 2 shows that the Victorian annual catch was moderately able at about 3 million lb. from 1911 to 1929. The Tasmanian output as similar, at least in the second decade. From 1930 to 1938 the mean nual Victorian catch increased, and the Tasmanian catch declined, both about 1.5 million lb. In 1939 and 1940 the catch declined sharply in th States. It then recovered rapidly in Tasmania, reaching 6 million n 1945-46. The Victorian catch remained fairly low until 1945-46, en 7.5 million lb. were caught. Australian production in 1945-46 was record with over 14 million lb., more than double that of the general el of the 'thirties. In 1946-47 the figures fell for both States. In 47-48 the Victorian catch declined further but that for Tasmania was record, and the total was 12.6 million lb. These figures are only the tches recorded by fishermen in their returns, and many men freely mit that these are under-statements.

As shown above, the Tasmanian annual catch figures cannot be ssected at present by fishing areas, except for 1941-42, 1942-43, and (with less accuracy) 1943-44. In those years the south-eastern area, which extends from the southernmost part of the State to Triabunna, accounted for 68, 59, and 54 per cent. respectively of the total catch; the north-western area, comprising the north coast west of the Tamar River, for 28, 35, and 32 per cent.; whilst other waters, mainly in the north-east, yielded 4, 6, and 14 per cent.

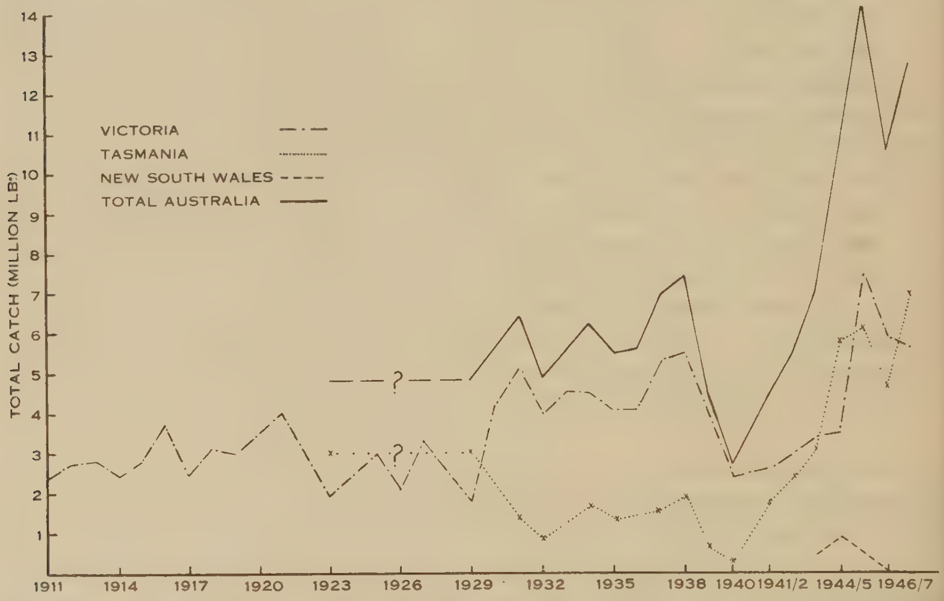


Fig. 2.—Annual recorded barracouta catches for Victoria, Tasmania, New South Wales, and all combined (i.e., total Australia), as far as available, 1911—1947-48 inclusive. For Tasmania 1923 is the only year before 1929 for which there is any information, but the annual catch is believed to have been fairly stable in the intervening period, and this has been indicated. As the Victorian catch was also moderately stable over this period, the same has been indicated for the total Australian catch. For further explanation see text.

In Victoria the principal fishing areas were formerly off Port Phillip and west of Cape Otway, the important centres being Queenscliff and Port Fairy. The position has changed considerably since the late 'thirties, and is shown in Table 3.

The geographical order of the Victorian ports, from west to east along the coast, is that in which they appear from left to right in Table 3. Apollo Bay, Lorne, and Westernport have recently greatly increased their barracouta landings, but the south-east and eastern waters still contribute only a small proportion of the catch. Over the entire period of record, at least 83 per cent. of the Victorian catch has been taken on the western half of the coastline. Obviously this area has a history of much more intensive and sustained barracouta fishing than even all Tasmania.

Therefore, if any evidence of depletion of barracouta due to overfishing is to be looked for, it would most logically be in western Victoria. The Victorian Yearbooks give the annual numbers of licensed fishing boats operating from the different ports, and these are shown in Table 4, together with the recorded catches, for the above-mentioned five centres. The total catch for each of these places is shown in Fig. 3(*A*), and the mean catch per boat, for each except Westernport, in Figure 3(*B*).

TABLE 3

MEAN ANNUAL RECORDED BARRACOUTA CATCH (THOUSANDS OF LB.), AND PERCENTAGE OF TOTAL VICTORIAN CATCH, LANDED AT THE STATED PORTS FOR SUCCESSIVE 6-YEAR PERIODS

Period	Port Fairy		Apollo Bay		Lorne		Queenscliff		Westernport		All Others	
	Catch	%	Catch	%	Catch	%	Catch	%	Catch	%	Catch	%
1912-1917	973	34.3	—	—	—	—	1,362	48.1	40	1.4	459	16.2
1918-1923	1,360	44.4	—	—	1	—	1,088	35.5	95	3.1	521	17.0
1924-1929	1,029	40.8	—	—	—	—	1,038	41.2	70	2.8	382	15.2
1930-1935	1,286	29.2	113	2.6	30	0.7	2,271	51.6	215	4.9	488	11.1
1936-1941	765	19.5	340	8.6	643	16.4	1,504	38.3	361	9.2	316	8.0
1942-43—1947-48	488	10.2	896	18.7	789	16.4	948	19.8	1,184	24.7	493	10.3

At Westernport, there are many boats which do not fish for barracouta at all. The same is true of some boats at Queenscliff and Port Fairy (see below). At Lorne and Apollo Bay all boats fish almost exclusively for barracouta.

For each port, the catch per boat curve is extremely similar to that of the total catch curve. The position as regards the former may be summarized as follows:

Port Fairy.—General stability for at least 20 years, followed by a gradual decline.

Apollo Bay.—A substantial increase over the whole history of the fishery (about 15 years).

Lorne.—A sharp increase followed by an irregular decline at a high level (total period about 12 years).

Queenscliff.—General stability for at least 18 years and at a much higher level for about 7, followed by a decline and, latterly, limited recovery.

Westernport.—Although there are no useful annual indices, it can be shown that the catch per boat has risen sharply over the last decade. The total catch curve shows that production did not become important until 1942-43. It is known that virtually all boats added to the fishery since then have fished mainly for barracouta. The mean annual number of boats for the period 1942-43 to 1946-47 was 141, an increase of about 20 per cent. over the figure for the previous quinquennium, which was 117

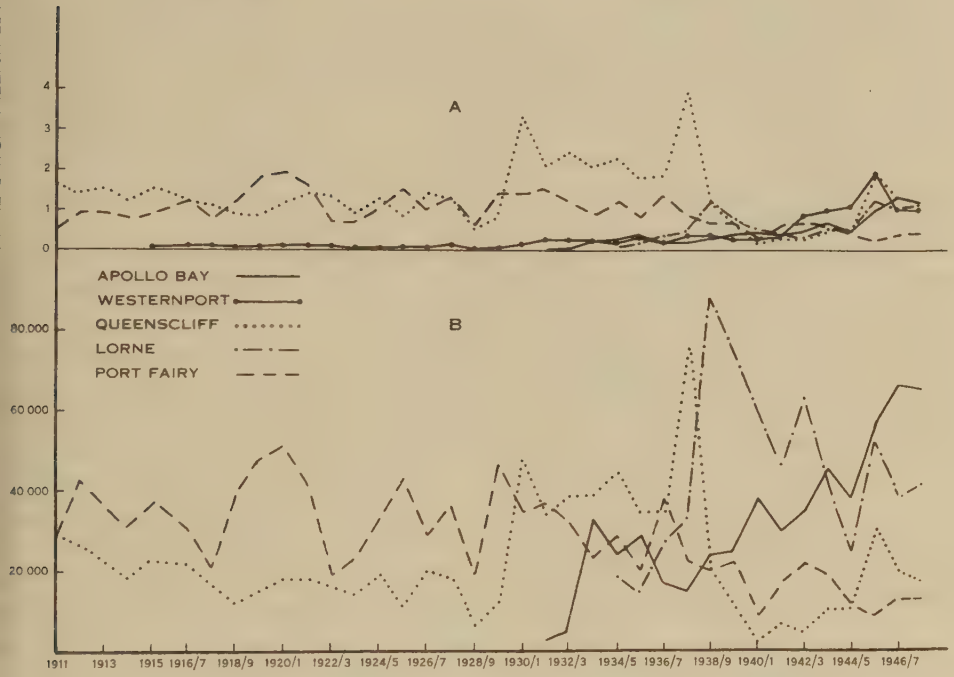
TABLE 4

RECORDED BARRACOUTA CATCH (THOUSANDS OF POUNDS), NUMBER OF BOATS, AND MEAN CATCH PER BOAT FOR VICTORIAN PORTS

Year	Queenscliff			Port Fairy			Lorne			Apollo Bay			Westernport	
	Catch	Boats	Catch per Boat	Catch	Boats	Catch per Boat	Catch*	Boats	Catch per Boat	Catch*	Boats	Catch per Boat	Catch	Boats
1911	1,572	51	31	532	19	28							1	52
1912	1,435	53	27	858	20	43							5	59
1913	1,469	65	23	860	24	36							12	89
1914	1,198	67	18	787	25	31							18	104
1915	1,512	66	23	883	24	37							34	69
1916-17	1,203	55	22	1,239	40	31							99	66
1917-18	1,110	67	17	761	36	21							93	90
1918-19	918	75	12	1,249	32	39							68	94
1919-20	930	63	15	1,839	38	48							75	99
1920-21	1,193	67	18	1,932	38	51							128	166
1921-22	1,356	75	18	1,628	39	42							98	99
1922-23	1,296	83	16	748	39	19							124	87
1923-24	878	64	14	724	31	23							32	92
1924-25	1,257	67	19	963	30	32							50	89
1925-26	770	72	11	1,469	34	43							78	97
1926-27	1,371	68	20	969	34	28							39	99
1927-28	1,270	70	18	1,300	36	36							137	102
1928-29	481	74	6	650	34	19							48	100
1929-30	840	73	12	1,445	31	47							63	106
1930-31	3,343	69	48	1,383	40	35							160	115
1931-32	2,107	62	34	1,513	41	37				17	6	3	256	119
1932-33	2,436	62	39	1,267	40	32				43	9	5	249	70
1933-34	2,138	55	39	865	38	23				229	7	33	261	104
1934-35	2,258	51	44	1,151	40	29	75	4	19	288	12	24	216	104
1935-36	1,841	52	35	787	40	20	228	15	15	402	14	29	298	95
1936-37	1,937	56	35	1,365	36	38	409	15	27	220	13	17	230	94
1937-38	3,894	52	75	854	38	22	457	14	33	194	13	15	416	99
1938-39	1,212	58	21	684	35	20	1,154	13	89	333	14	24	410	104
1939-40	580	49	12	698	32	22	826	11	75	356	14	25	339	114
1940-41	196	59	3	312	33	9	597	10	60	469	12	39	339	138
1941-42	311	46	7	561	33	17	530	13	46	424	14	30	426	129
1942-43	296	65	5	743	34	22	257	4	64	494	14	35	880	139
1943-44	454	47	10	604	31	19	476	11	43	730	16	46	1,082	126
1944-45	542	50	11	378	33	11	517	21	25	537	14	38	1,148	143
1945-46	1,865	63	30	342	38	9	1,319	25	53	1,032	18	57	1,920	143
1946-47	1,343	68	20	438	35	12	1,018	27	38	1,341	20	67	1,063	155
1947-48	1,186	71	17	421	34	12	1,147	27	42	1,241	19	65	1,008	175

* Earlier figures small and irregular.

(see Table 4). However, the corresponding increase in the mean barracouta catch was from about 0.4 to 1.2 million lb., or 300 per cent.



ig. 3 (A).—Annual recorded barracouta catches for each of the five main Victorian centres, as indicated, 1911—1947-48 inclusive.

B).—Annual recorded barracouta catches divided by total numbers of fishing boats censed in the different years, for the same centres, excluding Westernport. Not all these boats fished for barracouta. For further explanation see text.

There are thus three centres for which the catch per boat has at rst sight declined, and two for which it has risen. Further clarification possible from knowledge of local conditions, which can be summarized follows:

Port Fairy.—Since the early 'thirties increasing numbers of craft have been diverted to shark fishing. This was probably partly due to a decline in the demand for Port Fairy barracouta, which are held to be of relatively poor quality and which travel a long distance to the Melbourne market. The figures for barracouta catch per boat for the later years are therefore too low, and probably there was no decline in the index at all.

Apollo Bay.—The demand from this centre has recently been very firm. Most of the catch at present is being bought for fish paste and loaf preparations. In these guises, barracouta is more saleable than it is as fresh or smoked fish. For this reason, the general fall in the catch after 1945-46 did not affect this port (see below).

Lorne.—Since this is only about 25 miles from Apollo Bay the different catch per boat trends do not indicate real differences in the trend of fish abundance. The decline is known to be partly due to the fact that processors who formerly bought large quantities here now deal mainly with Apollo Bay (because of the more co-operative attitude of the fishermen). The catch per boat of 1946-47 and 1947-48 was still as high as that of Queenscliff or Port Fairy in their best periods.

Queenscliff.—This is about 60 miles north-east of Apollo Bay and 30 miles west of Westernport, which makes the decline here suspect as regards any real trend in fish abundance. The unproductive period about 1940 and 1941 was apparently due to natural fluctuation (see Section IV) but this does not explain the limited extent of the subsequent recovery. Some boats fish exclusively or mainly for shark, and this has depressed the indices for the last decade. The main explanation is probably that the demand for barracouta as table fish, at prices acceptable to the fishermen, is always limited, and that Queenscliff now has to share the Melbourne market with other centres, particularly Westernport and Lorne, which were unimportant before (Table 3 and Fig. 3). Queenscliff operators have in recent years been operating under a voluntary system of catch "limits." This has also happened at Lorne, but much less so at Apollo Bay and Westernport, where the demand is buoyant. These limits have often been very low, e.g., two or three boxes per man per day at the height of the season (Plate 2).

Westernport.—The demand for fish from this district has recently been very firm, although the catch declined a little after 1945-46. The fish are recognized in the market as being of above average quality. During 1948, New South Wales and Tasmanian canneries commenced buying fish from this centre.

None of these data provide evidence of a sustained decline in barracouta abundance at any stage in the history of the fishery. On the contrary, the trends in catch and catch per boat are either upwards or stable, or irregular in a manner which suggests the operation of other factors. Natural fluctuation and weather are among these factors, but there is ample evidence to show that the main one is that of demand. This is practically unquestioned in the industry, and the existence of a well-organized system of boat limits is most significant. The ports at which mean boat catches have declined are those at which limits are most often in force, and they are also those which have recently lost part of their market to other centres. By raising prices, these limits are supposed to compensate the fishermen for a reduced turnover. The critical fact is that barracouta is held in only limited esteem, as fresh or smoked fish, by consumers. Consumption increased in the late war years, when competing Australian and imported fish products were less available, but has since declined. Of the four main catching centres—Westernport, Queenscliff, Lorne, and Apollo Bay—the only one whose output has not declined since 1945-46 is Apollo Bay, the catch of which is mainly processed.

The demand factor is again the main cause of the variations in the Tasmanian barracouta catch. The recognition of this helped to make possible the expansion of the Tasmanian fishery which began during the war. Late in 1943 there was a proposal, by the Controller of Fisheries (Dr. H. Thompson) in the Commonwealth Department of War Organization of Industry, to approve the raising of capital for new fish canneries in Tasmania. This was strongly opposed in certain quarters, where it was alleged that the stock of barracouta, which it was clear would be the main species canned in the immediate future, was already depleted. It was believed that this statement was not correct. Early in 1944 it was submitted to the Controller of Fisheries that:

(*a*) The only evidence brought forward in support of the depletion hypothesis was the decline in the Tasmanian barracouta catch from the 'Twenties to the 'Thirties—evidence of a kind which is always suspect without data on fishing effort.

(*b*) It was almost universally held in the industry that this fall had been caused by a decline in the demand for Tasmanian barracouta in the principal market, Melbourne, following the expansion of the Victorian fishery.

(*c*) Many barracouta boats had been changed over in the 'Thirties to catching crayfish, for which the interstate demand had remained firm. This was shown by the increased average number of boats licensed annually to use crayfish pots, while the total number of vessels had remained about the same. As crayfish boats do little barracouta fishing, the number available for the latter activity had therefore fallen (see Table 5).

(*d*) The Tasmanian barracouta catch could therefore be increased at least to the 3 million lb. level of the 'Twenties if more boats were made available, by new building or by transfer from crayfishing. Crayfish was held to be non-essential, whereas canned barracouta was required for the armed forces.

After consideration of this, the development of new canneries was llowed to proceed in Tasmania. Also, earlier tentative decisions to lace barracouta fishing on a much higher priority than crayfishing (for allocation of manpower, scarce materials, and shipping space for ransport to the Australian mainland) were reaffirmed. Following representations by Tasmanian and C.S.I.R. fisheries officers, the Tasmanian manpower authorities had already adopted a policy, regarding call-up of fishermen, which was much more generous to the industry than that adopted in the other States. Because of all this, and especially because of the great demand for barracouta for both the fresh fish trade and canning, the number of men and vessels fishing for that species increased very rapidly, as did the catch. Within eighteen months the yearly rate of catch was twice that of the 'Twenties. This was the best response in the whole Australian fishing industry to the wartime demand for more fish.

TABLE 5

NUMBERS OF TASMANIAN FISHING BOATS LICENSED TO USE CRAYFISH POTS, TO TAKE FISH BY OTHER MEANS, AND BOTH COMBINED, BY YEARS

Year	Boats Licensed for Crayfish Pots	Boats Licensed for Other Fishing*	Total
1926	38	212	250
1927	69	180	249
1928	49	170	219
1929	48	192	240
1930	48	212	260
1931	55	214	269
1932	61	182	243
1933	66	168	234
1934	64	145	209
1935	69	155	224
1936	71	134	205
1937	87	121	208
1938	89	137	226
1939	87	148	235
1940	84	174	258

* Including estuarine fishing, etc. Not all of these boats would have been suitable for barracouta fishing.

Evidence in elaboration of (*b*) above was later procured by J. A. Tubb. He obtained: (i) records of exports of all fish (excluding crayfish and oysters) from Tasmania for 1905-1909 and 1922-23—1940-41, from the Hobart office of the Commonwealth Bureau of Statistics; and (ii) records of Victorian imports of similar fish from Tasmania, for 1906-1940, from the Superintendent of Markets of the Melbourne City Council. These are given in Tables 6 and 7 and in Figure 4. These records refer almost entirely to barracouta. It is clear that, in the 'Twenties, the largest proportion of Tasmanian fish exports was to Victoria, and that the volume of business done with Victoria declined after 1929 and greatly curtailed the Tasmanian export trade. For both total Tasmanian exports and Victorian imports from Tasmania the level of the 'Thirties was about 1¼ million lb. a year below that of the

'Twenties. It was shown previously that the annual Tasmanian catch of barracouta was about 1½ million lb. less in the 'Thirties and the Victorian catch the same amount more. Obviously, the situation was that increased Victorian production displaced the very large proportion of the Tasmanian catch that had hitherto found an outlet in the Melbourne market; and that, as alternative markets were not available, Tasmanian fishermen did not catch as much barracouta as previously.

TABLE 6

EXPORTS OF ALL FISH (NOT CRAYFISH OR OYSTERS) FROM TASMANIA

Year	Fish (lb.)
1905	426,971
1906	474,946
1907	514,376
1908	982,711
1909	715,749
1922-23	1,499,344
1923-24	2,386,720
1924-25	1,600,256
1925-26	1,707,440
1926-27	1,734,656
1927-28	1,429,680
1928-29	1,874,992
1929-30	1,506,288
1930-31	942,256
1931-32	839,664
1932-33	711,872
1933-34	603,680
1934-35	656,880
1935-36	371,504
1936-37	324,240
1937-38	473,536
1938-39	409,472
1939-40	979,664
1940-41	917,504

Vith the falling fish prices of the "depression" years, Tasmanian fish ealers, with steamer freights to reckon with, could not compete with ictorian fishermen landing their catches within a relatively short istance from Melbourne, and with reasonably good land transport vailable to them. During the 'Thirties the Victorian fishermen gained urther advantages as motor transport improved and as better roads vere built. In particular, the opening of the Great Ocean Road made it ossible for Lorne and Apollo Bay men to get large quantities of fish uickly to Melbourne.

With the great demand for fish of any kind that arose towards the end of the war, Tasmanian barracouta dealers had one more opportunity of selling barracouta on a large scale to Victoria, before the Victorian catch itself increased. This was mainly in 1944-45 (see Fig. 2). The fact that the Tasmanian catch rose so greatly a full year before the Victorian was probably due to the additional manpower available to the Tasmanian industry. As soon as the war ended, the Melbourne outlet for Tasmanian fish again rapidly diminished as Victorian fishermen

TABLE 7
VICTORIAN IMPORTS OF ALL FISH (NOT CRAYFISH OR OYSTERS) FROM TASMANIA

Year	Fish (lb.)
1906	91,840
1907	85,610
1908	493,920
1909	445,410
1910	477,610
1911	522,970
1912	432,740
1913	480,900
1914	638,050
1915	967,470
1916	796,460
1917	1,097,320
1918	473,970
1919	118,580
1920	577,080
1921	212,870
1922	372,890
1923	1,425,480
1924	1,354,360
1925	840,980
1926	1,639,540
1927	889,350
1928	969,990
1929	1,365,000
1930	945,910
1931	482,230
1932	446,950
1933	283,920
1934	142,240
1935	129,360
1936	87,990
1937	75,320
1938	113,820
1939	107,730
1940	220,570

overtook the local demand. Tasmania also found an outlet for barracouta in New South Wales, where the demand, never very good, had risen in the absence of the trawling fleet on war service. However, this soon fell off after the war, as the curve of the New South Wales catch itself indicates. By 1946-47, the Tasmanian catch was declining. It rose to a new record in 1947-48 because of the increased demand for barracouta by Tasmanian canning firms, now four in number (as compared with only one, part-time, before the war and only one, part-time, at any time in Victoria). These firms produced straight canned packs as well as fish paste. The former are now mainly exported to the United Kingdom.

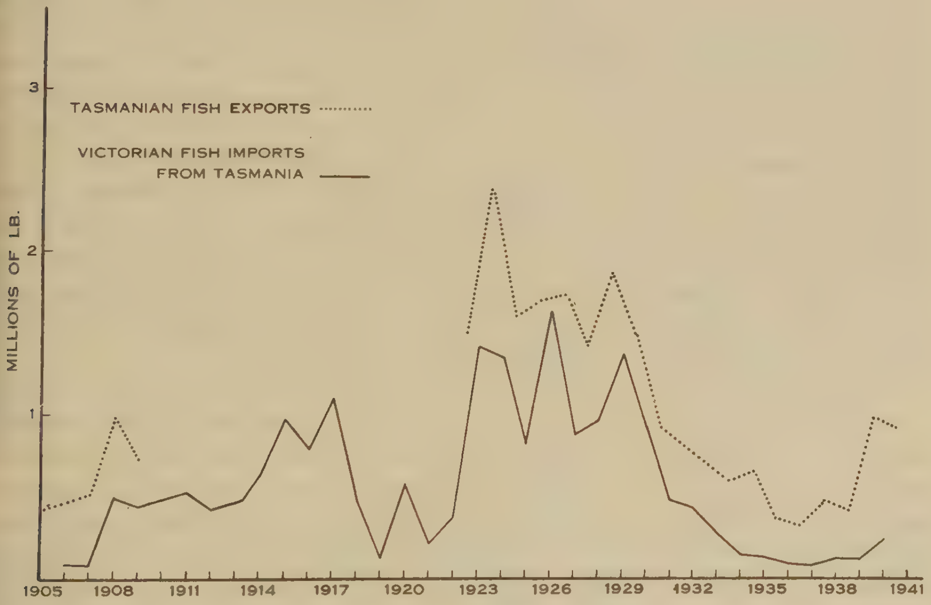


Fig. 4.—Annual Victorian imports of Tasmanian fish, 1906-1940, and annual exports of Tasmanian fish, 1905-1909 and 1922-23—1940-41. These figures do not include crayfish and oysters.

Unfortunately, the numbers of boats engaged in the Tasmanian ishery are not readily available. It is well known, however, that the arracouta fleet did increase considerably from 1943 onwards, by new uilding and transfers from other fisheries. This probably stimulated roduction in more ways than one, because of involuntary co-operation etween boats. The more boats there are in an area, the more certain it s that at least one, followed by the rest, will find the fish in plenty. ome dealers limited the catches in 1945 and 1946, when cold stores were ull and shipping space to the mainland was inadequate.

IV. ABUNDANCE AND AVAILABILITY OF BARRACOUTA: GENERAL CONSIDERATIONS

The evidence submitted in the previous section disposes of any suggestion of depletion, through excessive fishing, of the barracouta stocks to date. Furthermore, barracouta is manifestly an abundant species in the southern Australian seas in most years. Boats seeking barracouta rarely go long without finding them, in season, and many of the schools are too large to be effectively reduced by the small fleets and primitive fishing gear opposed to them. There are also great areas of coastal waters in which barracouta occur but in which little fishing is done. Even leaving aside South and Western Australia, there are many large sections of coastline which are virtually untouched, mainly for lack of harbours on which boats can be based; e.g., most of that between Port Fairy and Cape Otway, all of that between Westernport and Wilson's Promontory, the greater part of the east coast of Victoria, much of north-east Tasmania and the adjacent islands, King Island, and all the Tasmanian west coast. At the stage at which it is commercially useful, the barracouta is an open-sea fish; but, alone among such fish which are important in the Australian catch at present, it is sought only by vessels which operate very close to their home ports, for the most part carrying no ice, and using gear which permits considerable escape. Most of this is again a function of the limited demand.

However, the barracouta stocks probably have not been entirely unaffected by fishing operations. It is fairly well known in the industry that the fish caught in western Victoria (possibly excluding Westernport) are smaller in average length than those taken in southern Tasmania. Evidence in the form of thousands of measurements is also available to show this. These two areas produce the largest catches, but the fishery has been far more vigorously and regularly carried on in the former region. This strongly suggests that the western Victorian fishery takes a greater proportion of the stock available to it than does that of southern Tasmania, so that fewer fish live to reach the large sizes. In northern Tasmania the average size is less than in the south, which is well known in the industry and can also be demonstrated from measurement data. This is not at first sight so easy to understand, as the north has probably been less intensively exploited than the south. However, there are a few indications that the stock of fish available in northern Tasmania might be the same as that of western Victoria (i.e., a continuous population across western Bass Strait), and that the southern Tasmanian fish belong to a different group, which could explain the facts observed. The possible existence of more than one population of barracouta in the present area of the fishery and the geographical extent of each if such populations exist are the main matters now being investigated.

Some old accounts of barracouta fishing in southern Tasmania suggest that the average size was formerly greater, and the average weight substantially greater, than it is in that region to-day. Meredith (1881, p. 256), Tenison-Woods (1883, p. 57), Saville-Kent (1887), and Johnston (1883, p. 81; 1891, pp. 40-41) all quote round weights, some purporting to be general trade averages, from 6 to 10 lb. per fish. This is about double the present-day figure. Meredith, Tenison-Woods, and Johnston also mention lengths from 3 to 4 feet. The present-day mean total length is only about 3 ft., and fish at 4 ft. are rare. It is thus probable that even the stock of southern Tasmania has been appreciably affected by fishing operations. Possibly there was an initial accumulation of very old fish, which was gradually removed during the nineteenth century. This might well have been beneficial to the stock as a whole because barracouta often eat their own young, and probably compete with them for food.

Natural fluctuations in abundance, or merely in availability in the areas accessible to the fishermen, are believed to be important in the barracouta stocks. It is hoped that the current biological work will throw more light upon this problem. The low catch level of 1940 and 1941, when the fish were in keen demand for canning for the services, was due to some type of natural fluctuation. The general opinion among fishermen was that the fish were present but were refusing to bite. Most fishermen believe that refusal to bite is liable to affect the catch of a whole season.

V. ACKNOWLEDGMENTS

The author desires to thank a former colleague, Mr. J. A. Tubb, for his contribution to this work. Mr. Tubb came more or less independently to similar conclusions about the condition of the barracouta fishery, but generously made his records available. His special contributions to the present study are indicated in the text.

Mr. T. J. Challenger, Inspector of Fisheries in Tasmania, first demonstrated to the author the significance of market demand on the Tasmanian catch. Mr. Challenger and Mr. R. H. Scott, who was then Secretary of the Tasmanian Fisheries Division, played an important part in bringing into existence and administering the particular group of fisheries controls which helped to make possible the great increase in the State barracouta catch during the war.

Plate 1 was photographed by Mr. W. G. Scott, of the Division of Fisheries, C.S.I.R.O. The line figures were drawn by Mr. K. Wilson, of that Division, under the supervision of A. Proctor. Plate 2 is by courtesy of the Victorian Fisheries and Game Department.

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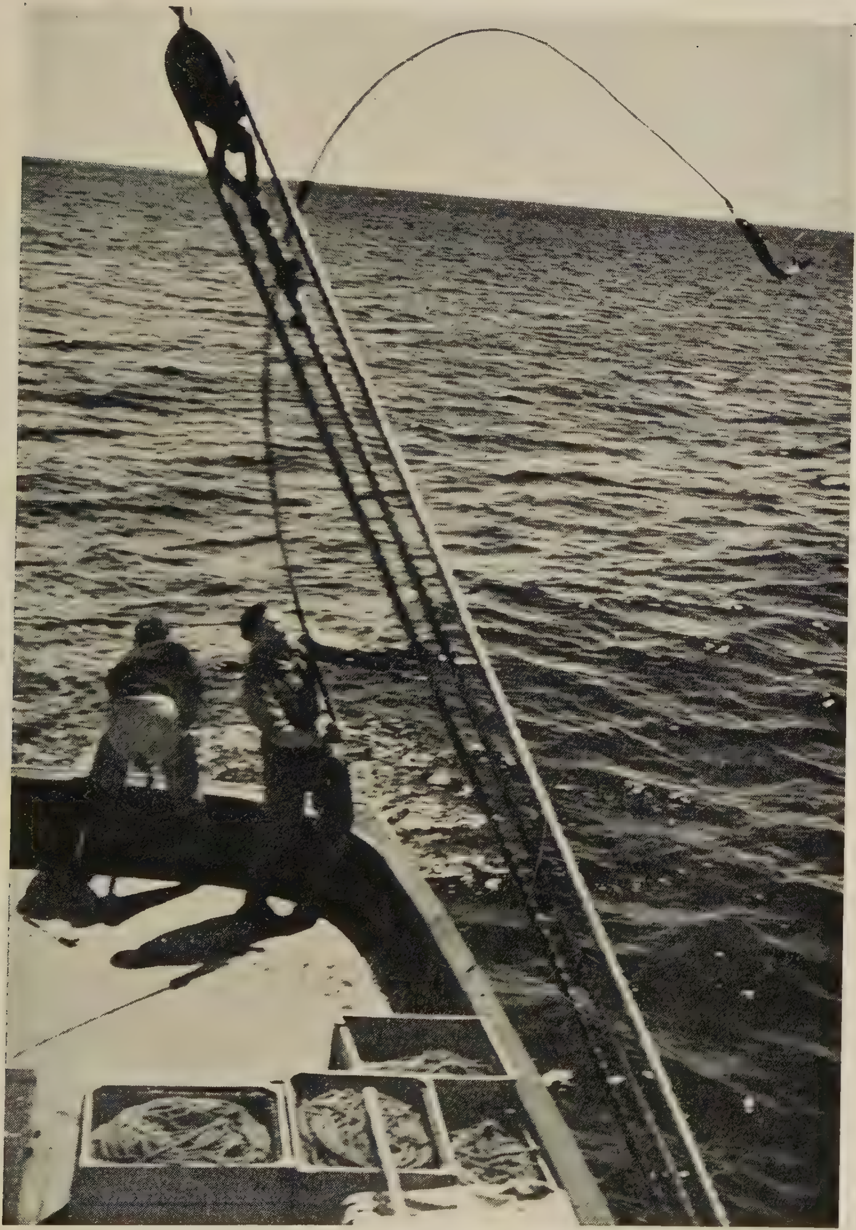
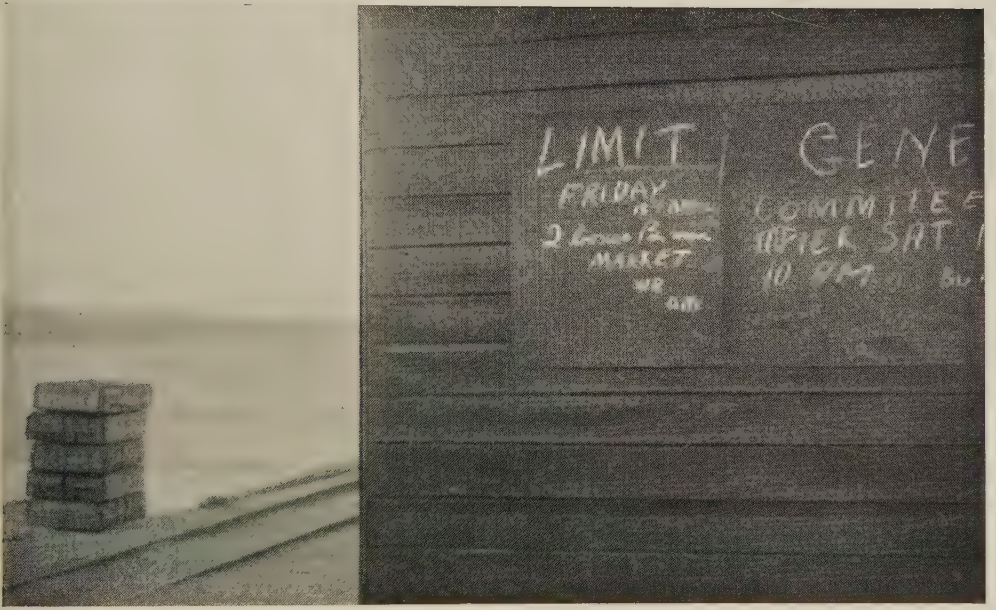


Fishing for barracouta with the Tasmanian jigstick. This photograph was taken aboard the C.S.I.R.O. research vessel Liawenee. Commercial barracouta boats are much smaller.


LIMIT
FRIDAY
MARKET
GENE
COMMITEE
PIER SAT
10 PM

Notice to fishermen of limits for barracouta, on the pier at Lorne, Victoria.

THE BACTERIOLOGY OF SHARK SPOILAGE

By E. J. FERGUSON WOOD*

[*Manuscript received October* 27, 1949]

Summary

The spoilage of shark is considered on present evidence to be due to autolysis and bacterial action, but the relative importance of each is not known.

Spoilage is regarded as due to production of ammonia from urea and other nitrogenous bodies present in shark flesh, as well as to the formation of less volatile substances.

The genera *Corynebacterium, Micrococcus, Sarcina, Pseudomonas, Bacillus, Enterobacter, and Mycoplana* are recorded as well as a *Torula*.

The flora is regarded as a modified marine flora in which the Gram-positive elements have been greatly enriched, with the Gram-negative of little importance. It resembles a mud flora rather than one from sea-water.

I. INTRODUCTION

In 1943, the author began a study of shark spoilage, shark having ome an important food fish in Australia, while the livers were in great nand for vitamin oils. Shark spoilage results in the production of monia at a relatively early stage, in concentrations sufficient to give fish a metallic flavour. The amount of other volatile amines seems to y even in fresh shark flesh. It is the ammonia, therefore, which decides saleability or otherwise of the product.

Unfortunately, owing to more important work, the investigation could carried on only to the stage where recommendations for commercial trol measures could be issued. Latterly, however, shark spoilage investi-ion has been resumed.

II. THE ROLE OF BACTERIA IN SHARK SPOILAGE

At first it was thought that bacteria were the main cause of spoilage shark flesh and that the ammonia was derived from the urea which is sent in normal shark flesh to the extent of about two per cent. The res for the urea content of various parts of elasmobranchs vary con-erably, and the author believes that this is due to urea being part of ornithine cycle. Hunter (1929) reports arginase in shark liver and t, and the author has found urease in blood and flesh so that the duction of ammonia during spoilage may in part be due to autolysis. monia can be produced from sterile flesh by adding sterile shark blood, the rate of production does not seem sufficient to account for spoilage mally found. At the same time, there were isolated from shark flesh bacteria which can liberate ammonia from autoclaved shark flesh, shark muscle juice, urea agar, meat extract, peptone, and asparagin, so these microorganisms must be considered as a factor in spoilage, though probably not the sole cause. They occur largely on the cut surfaces, the numbers decreasing sharply with depth below the surface. They can also penetrate more slowly through the skin after death. The bacteria associated with shark spoilage are strongly aerobic and grow only slowly under anaerobic, or even micro-aerophilic, conditions, while their capacity to split urea likewise decreases with a decrease in oxygen tension. The decrease is obvious with 25 per cent. carbon dioxide, and growth in pure carbon dioxide or hydrogen is very slow indeed.

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* Division of Fisheries, C.S.I.R.O.

III. COMPARISON OF ELASMOBRANCH AND TELEOST SPOILAGE FLORAS

The flesh of freshly caught shark was found to be sterile as is the case with teleost fish. Gee (1930) reported bacteria in the flesh of haddock, but this has never been confirmed. Bisset (1948) likewise records the presence of bacteria in the flesh of live freshwater fish. If this should be confirmed, it will be an interesting difference between freshwater and marine fish. Bacteria are, however, present in the gills and on the skin of snapper shark, saw shark, and angel shark, and these are of the same type as those found in the flesh of spoiling shark and in the holds of fishing vessels.

It is interesting, therefore, to consider the bacteria found in spoiling shark muscle, and also their origin. The flora differs somewhat from that found by the author (1940) in spoiling teleost fish. In comparing the shark flora with the teleost flora recorded in the paper mentioned above, the Gram-positive rods recorded as *Flavobacterium* and *Achromobacter* are now recognized as *Corynebacterium*, and many of the Gram-negative forms listed as *Achromobacter* are to be regarded as *Mycoplana*. Moreover, it was stated that there appeared to be a number of organisms that did not satisfactorily fit Bergey's classification. It is now considered that the majority of species of the genera *Achromobacter*, *Flavobacterium*, and *Micrococcus*, which are listed in Bergey's 5th Edition, are not sufficiently distinct to warrant specific rank, so that the number of species active in fish spoilage is relatively small. If this is accepted, the species concerned in spoilage of teleosts and elasmobranchs are much the same, although the relative abundance of the species is different.*

With teleost fish, a succession of genera was observed during spoilage (Wood 1940; Aschehoug and Vesterhus 1940), and this was also found in crayfish spoilage by Alford, Tobin, and McClesky (1942). It does not, however, appear in elasmobranch spoilage.

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* One important difference is the absence of true *Achromobacter* and the comparative rarity of Gram-negative forms.

IV. CHARACTERISTICS OF THE FLORA

A large majority of the bacteria isolated contained an active urease, while many of them attacked peptone, meat extract, asparagin, and other bodies with an amino-group, liberating ammonia. The fermentation of sugars varied considerably within each genus, so much so that this character was considered useless in delimiting species. Bacteria from marine sources seem to liquefy gelatin much less frequently than corresponding land forms, and this applies equally to the forms isolated from shark flesh. Indol positive organisms were very rare. Starch was often hydrolysed and hydrogen sulphide production from tryptone agar was frequent. Catalase production was very common. Most strains grew equally well on freshwater and sea-water agar, but had a wide temperature range—up to 37°C. and often as high as 45°C.

It is possible that some bacteria which are apparently unreactive in pure culture become active by synergic effort with other bacteria and that changes difficult to demonstrate by pure culture technique occur in this way.

V. THE SPOILAGE FLORA OF SHARK FLESH

The following genera and species were isolated from shark:

(*a*) *Genus* Corynebacterium

This genus is regarded by the author as including all non-sporing, non-motile, Gram-positive rods, and those which are motile and show polar lagella, provided that they show snapping cell division. They are requently, probably normally, pleomorphic, non-acid fast, and often show metachromatic granules when stained by Neisser's method. Many of the Gram-positive forms reported by Thjøtta and Sømme probably belong o this genus.

TABLE 1

REACTIONS OF *CORYNEBACTERIUM HELVOLUM* STRAINS

Litmus milk acid	6 strains	Glucose acid	21 strains
Litmus milk alkaline	18 strains	Lactose acid	3 strains
Casein digested	17 strains	Saccharose acid	16 strains
Litmus reduced	29 strains	Maltose acid	13 strains
Gelatin slowly liquefied	11 strains	Mannitol acid	21 strains
Starch hydrolysed	21 strains	Laevulose acid	20 strains
Nitrates reduced to nitrite	21 strains	Galactose acid	19 strains
Urea decomposed	45 strains	Glycerol acid	9 strains
		Inulin acid	3 strains
		Salicin acid	9 strains
		Raffinose acid	4 strains
		Xylose acid	8 strains

Isolations from shark flesh and skin numbered 174 strains. As the ecies were represented on the skin of live sharks, they can be regarded marine.

Corynebacterium helvolum (Zimmerman) Kisskalt and Berend.—Fifty-one cultures were isolated from shark flesh and skin. All were Gram-positive, polymorphic rods, frequently showing coccoid forms and cystites, occasionally branching. All strains showed snapping cell division by the slide culture method of Topping (1937). Six strains were motile, but otherwise fitted into the genus. Topping also records motile strains of soil bacteria which probably belong to this species.

All strains were lemon to canary yellow on agar, with rather abundant growth and a characteristic contoured appearance. Colonies were shiny at first, later becoming rather dull and somewhat granular. All were catalase positive, and the majority produced ammonia from urea. Table 1 gives the reactions of the strains. No correlation between these characters could be shown, so it was not possible to subdivide the species even into races.

Corynebacterium globiforme (Conn) n. comb.—The 59 strains isolated from shark skin and muscle appear to fit into the *B. globiforme* group. Since slide cultures of a number of strains showed snapping division, it seems clear that this organism is *Corynebacterium* as suggested by Conn (in Bergey *et al.* 1948). The difficulty of accepting this genus for these forms has been due largely to the motility of a number of strains as recorded by Taylor (1938). However, Topping has recorded motile *Corynebacterium*-like strains and this nas been confirmed by the author (see above). These motile strains are in the same category as the motile forms of *Sarcina* and of *Micrococcus* which are well recognized. Eight strains were motile. Morphologically, they were polymorphic. Cystites were frequent, and coccoid forms predominated.* The reactions of the strains are given in Table 2. No correlation could be found which would adequately separate races or strains.

TABLE 2

REACTIONS OF *CORYNEBACTERIUM GLOBIFORME* STRAINS

Litmus milk acid	12 strains	Lactose acid	4 strains
Litmus milk alkaline	16 strains	Saccharose acid	8 strains
Casein digested	7 strains	Maltose acid	13 strains
Litmus decolorized	10 strains	Mannitol acid	7 strains
Gelatin liquefied	10 strains	Laevulose acid	9 strains
Nitrates reduced	18 strains	Galactose acid	9 strains
Starch hydrolysed	12 strains	Glycerol acid	3 strains
Urea decomposed	23 strains	Inulin acid	1 strain
Catalase positive	59 strains	Salicin acid	7 strains
Glucose acid	22 strains	Xylose acid	7 strains
		Raffinose acid	2 strains

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* No pigment was produced on agar and the colonies were transparent to semi-opaque, slimy to mucoid.

Corynebacterium erythrogenes (L. and N.) Kisskalt and Berend.—Twenty-four strains were isolated from shark skin and flesh. These were all Gram-positive coccobacilli or cocci with rod forms in slide culture, occasionally persisting. Branched forms were rare. Snapping division was observed in slide cultures, often giving the appearance of streptococci when in palisade arrangement. Two strains were motile with polar flagella. This species obviously belongs to *Corynebacterium*.

On agar, the cultures were lemon yellow, similar in appearance to *C. helvolum* except that a wine-red colour appeared in the agar after a few days. This pigment was also produced in gelatin and milk. All cultures were catalase positive. The reactions are given in Table 3. No strains were recognized.

TABLE 3

REACTIONS OF *CORYNEBACTERIUM ERYTHROGENES* STRAINS

Litmus milk acid	4 strains	Lactose acid	1 strain
Litmus milk alkaline	11 strains	Saccharose acid	7 strains
Casein digested	8 strains	Maltose acid	10 strains
Litmus decolorized	15 strains	Laevulose acid	10 strains
Gelatin liquefied	10 strains	Mannite acid	3 strains
Starch hydrolysed	11 strains	Galactose acid	5 strains
Nitrates reduced	14 strains	Glycerol acid	4 strains
Urea decomposed	18 strains	Inulin acid	0 strains
Glucose acid	11 strains	Salicin acid	3 strains
		Xylose acid	3 strains
		Raffinose acid	4 strains

Corynebacterium brunneum Kisskalt and Berend.—Twenty strains were isolated from shark flesh and skin. The morphology of this species was similar to that of *C. helvolum*, with coccoid forms, clubs, cystites, and a few branched forms. Snapping cell division occurred in slide cultures. Metachromatic granules occurred in some strains. Two strains were motile with polar flagella.

On agar, the colonies were orange or buff to brownish, with moderate

TABLE 4

REACTIONS OF *CORYNEBACTERIUM BRUNNEUM* STRAINS

Litmus milk acid	3 strains	Lactose acid	2 strains
Litmus milk alkaline	9 strains	Saccharose acid	11 strains
Casein digested	8 strains	Maltose acid	10 strains
Litmus decolorized	8 strains	Mannitol acid	10 strains
Gelatin liquefied	7 strains	Laevulose acid	9 strains
Nitrates reduced	9 strains	Galactose acid	5 strains
Starch hydrolysed	5 strains	Glycerol acid	2 strains
Urea decomposed	15 strains	Inulin acid	1 strain
Glucose acid	13 strains	Salicin acid	7 strains
		Xylose acid	2 strains
		Raffinose acid	4 strains

growth, sometimes abundant and resembling that of *C. helvolum,* contoured margin. All strains were catalase positive. Table 4 gives the reactions.

Corynebacterium flavum (Orla-Jensen) nov. comb.—Six strains were isolated from shark flesh in Victoria. All were Gram-positive rods with coccoid forms and snapping cell division. Three strains were motile.

On agar, the colonies were bright yellow, semi-opaque, with rather scanty growth. All reduced litmus, two acidified milk with coagulation, the other digested casein with an alkaline reaction. All liquefied gelatin slowly and all produced catalase. Four cultures reduced nitrate, two decomposed starch, three fermented glucose, two fermented saccharose, glycerol, and salicin, and one fermented inulin and one lactose. Raffinose, xylose, galactose, and laevulose were not fermented.

Corynebacterium miltinum Kisskalt.—Two strains, one from shark flesh, the other from skin, were isolated. These were Gram-positive, showing rod, club, and coccoid forms. Branched forms were rare; snapping division occurred; one strain was motile.

Agar colonies were brick-red to orange-red, moderate, raised, and shiny, later granular. Milk became acid, then alkaline, litmus was decolorized; gelatin was not liquefied in 28 days. One culture reduced nitrate to nitrite, and one hydrolysed starch and urea. The hexoses, mannitol, salicin, saccharose, and lactose were fermented. To this species some of the red forms recorded from fish by Thjøtta and Sømme may well be referred.

(*b*) *Genus* Micrococcus

Twenty-eight strains of this genus were isolated from the flesh and skins of sharks. The genus was more frequent in Victorian than New South Wales cultures. The same was noted in teleost spoilage. As the genus occurs on the skin of live fish, it can be regarded as of marine origin. Descriptions of species are based on Bergey *et al.* (1948) and deviations therefrom are noted. It is felt that even the latest and much improved classification is still too rigid.

Micrococcus candidus Cohn.—Nine strains of this species were isolated from shark flesh in Victoria. Two strains conformed to the description in Bergey, two strains were slightly saccharolytic, otherwise conforming to type, the other five strains differing from the description by reducing nitrates to nitrites. The author does not agree with Hucker as to the value of the reduction of nitrates as a specific test in this genus, at least as far as the marine, air, and spoilage forms are concerned. All were catalase positive.

Micrococcus caseolyticus Evans.—Seven strains were isolated from shark flesh.

All liquefied gelatin, reduced nitrate, and were catalase positive. Three cultures produced ammonia from urea. Sugar reactions varied somewhat. Glucose, saccharose, and maltose were fermented by all cultures, salicin by six, mannite and laevulose by four, lactose and glycerol by one.

Micrococcus flavus Trevisan.—Four strains from Victorian shark esh were isolated. Gelatin was liquefied, and glucose, saccharose, and naltose fermented by all strains, nitrates were reduced by three; milk ecame acid and coagulated; two strains fermented lactose, mannite, aevulose, galactose, and xylose also. All were catalase positive.

Micrococcus caseolyticus Evans (orange strains).—These strains vould seem to be colour variants of the seven non-pigmented strains escribed above. One, however, produced acid and coagulation in litmus nilk followed by slow digestion. All liquefied gelatin, decomposed urea, roduced catalase, and reduced nitrates. The strains were saccharolytic.

Micrococcus roseus Flügge.—One strain was isolated from Victorian hark flesh. This agrees with Bergey's description of *M. roseus*, except hat it failed to ferment any carbohydrates, but hydrolysed starch; nitrates vere not reduced and litmus milk was unchanged.

It may be possible that some of the divergences between these descriptions and those of Bergey *et al.* are due to the fact that some strains epresent Corynebacteria which do not show rod forms at any stage and re therefore unrecognizable. The writer considers that the relationships etween *Micrococcus*, *Sarcina*, and *Corynebacterium* are very close. Jensen as pointed out the relation between Corynebacterium and the other Actinomycetales and the author believes that the whole group of non-poring Gram-positive bacteria are closely related phylogenetically.

(*c*) *Genus* Sarcina

Sixteen strains of this genus were isolated. There is considerable ariation in the physiology of the marine strains of *Sarcina*, as will be een from the descriptions given below. It seems that, as in the case of *Corynebacterium*, pigment production is the only character which can be ised to separate species.

Sarcina flava De Bary.—Six cultures were isolated from shark flesh rom Victoria and South Australia.

These strains were bright yellow on agar, produced acid in milk, two coagulating; casein was slowly digested; only one culture liquefied gelatin n 28 days. Nitrates were reduced by four strains. All were catalase positive. Glucose, lactose, saccharose, and laevulose were fermented.

Sarcina lutea Schroeter.—Four cultures were isolated from shark kin and flesh. One culture arose as a stable variant from a strain of *Corynebacterium helvolum*.

These strains were sulphur yellow in colour, produced alkalinity in nilk, one liquefied gelatin slowly, three decomposed starch, one reduced itrate to nitrite, while all decomposed urea and produced catalase. Carbohydrate fermentation was poor: two cultures attacked glucose, two aevulose, and one maltose, one mannitol, and one saccharose.

Sarcina aurantiaca Flügge.—Four cultures were isolated from shark lesh and skin. All were buff to orange in colour, two produced acid in nilk, reduced nitrate and attacked glucose, saccharose, maltose, mannitol, laevulose, glycerol, and galactose. The other two gave an alkaline reaction in milk with digestion of casein, slowly liquefied gelatin, did not reduce nitrates, and fermented only glucose and maltose. All decomposed urea and produced catalase.

Sarcina candida Lindner.—Four cultures were isolated from shark flesh. This species is not pigmented, produces acid from litmus milk, does not liquefy gelatin, reduces nitrates to nitrites, is catalase positive and ferments glucose and saccharose.

(*d*) *Genus* Pseudomonas

Twenty-nine strains of this genus were isolated from flesh.

Pseudomonas fluorescens Migula.—Nine strains were isolated from shark flesh.

All cultures digested casein, liquefied gelatin, reduced nitrates to nitrites or ammonia, decomposed urea, were catalase positive, and fermented glucose but no other sugars.

Pseudomonas putida Trevisan.—Four strains were isolated from shark flesh and skin. They gave an alkaline reaction in litmus milk, one strain digesting casein; gelatin was not liquefied; urea was decomposed; acid was produced in glucose.

Pseudomonas chlororaphis (Guignard and Sauvageau) Bergey *et al.*—One strain with the reactions of this species was isolated from shark flesh. Its pathogenicity for laboratory animals was not tested.

Pseudomonas desmolyticum Gray and Thornton.—Eleven strains were isolated from shark flesh in Victoria. An acid coagulum was produced in milk by four strains, gelatin was not liquefied, nitrates were reduced by three strains, starch was not hydrolysed, indol was not produced, glucose and, at times, lactose and laevulose were fermented.

Pseudomonas boreopolis Gray and Thornton.—From the descriptions given, *Ps. putrefaciens* (Derby and Hammer) Long and Hammer would appear to be a synonym. Three strains liquefying gelatin and reducing litmus, in milk with alkaline digestion, were isolated from shark flesh. Of these, two reduced nitrates, all produced catalase, and none attacked carbohydrates.

Pseudomonas fragi (Eichholz) Huss.—One strain was isolated from shark flesh. This liquefied gelatin, produced an acid coagulum in milk and acid in glucose and catalase. It failed to reduce nitrate, produce diastase, produce ammonia from peptone or urea, or acid from any other carbohydrate.

(*e*) *Genus* Mycoplana

The Gram-negative, highly polymorphic organisms found in a marine environment are considered by the author to belong to Gray and Thornton's genus *Mycoplana*. This would include a number of organisms listed as *Vibrio* or *Pseudomonas* in works on marine bacteria, though *Pseudomonas* does also occur (see above). *Pseudomonas*, however, is far less polymorphic, is not granular in appearance, ferments glucose, and is on the whole more active in decomposing nitrogenous organic compounds.

Mycoplana dimorpha.—Two strains from shark flesh. These strains did not liquefy gelatin, produced alkali and then faint acid in milk, were catalase positive and were not fermentative.

M. dimorpha var. *aurantiaca.*—One strain was isolated. This strain reduced nitrate and fermented sugars.

Mycoplana bullata.—Four strains were isolated from shark flesh and skin. These slowly liquefied gelatin, produced alkaline reaction in milk, and decomposed urea. They varied in their action on carbohydrates, two strains being saccharolytic and two not.

Mycoplana flava.—Six strains were isolated from muscle and skin of sharks. Three were motile, gelatin was slowly liquefied by two strains, milk became slightly alkaline with or without digestion, nitrates were reduced by one culture; urea was decomposed, and glucose fermented by all.

Mycoplana rubra.—One strain was isolated from shark flesh. It agreed with the description given elsewhere (Wood, in press).

(*f*) *Genus* Proteus

Nine strains were isolated from shark flesh from trawlers.

Proteus vulgaris.—Eight strains were isolated. They agreed with Stuart and Rustigan's description.

One aberrant *Proteus* strain was isolated. This gave a small bubble of gas in glucose after 7 days, attacked urea, and resembled *P. vulgaris* except for its slow fermentation of carbohydrates.

(*g*) *Genus* Bacillus

Six strains of this genus were isolated from trawler-caught shark sampled in port. It is therefore doubtful whether these strains were of marine origin, as they could easily have been land contaminants.

Bacillus subtilis Cohn.—Two strains were isolated from shark flesh.

These strains differed from the description given in Bergey *et al.* (1948) in that one culture failed to reduce nitrates, the other to hydrolyse starch.

Bacillus lentus Gibson.—Two strains resembling *B. lentus* were isolated from shark flesh. These strains slowly digested casein, but were otherwise identical with *B. lentus.*

Bacillus sphaericus Neide.—Two strains were isolated from shark flesh. One strain slowly digested casein and hydrolysed starch, the other followed the recations given for *B. sphaericus* in Bergey *et al.* (1948).

(*h*) *Genus* Bacterium

Bacterium aerogenes.—Three cultures were isolated from trawled shark flesh.

(*i*) *Yeasts*

A pink Torula was isolated from the skin of a live shark in New South Wales waters. It produced acid in milk, liquefied gelatin, decomposed starch, reduced nitrate, decomposed urea, was catalase positive, and fermented maltose and laevulose.

VI. ECOLOGICAL RELATIONSHIPS OF THE SPOILAGE FLORA

All the genera except *Bacterium* and most of the species recorded have been found by the author in other marine environments. The flora is more closely related to that of muds than to that of sea-water. This might be expected as these sharks are mainly bottom feeders. From studies made, it would seem that, in spoilage, an enrichment of certain genera occurs, especially of Gram-positive types in elasmobranchs. The same enrichment of Gram-positive organisms occurs in teleost fish in the early stages of spoilage. The flora is thus much closer to a land flora than that of the open sea, though it lacks the large numbers of spore-formers found on land and also in estuarine muds.

The author believes that the spoilage flora of shark is marine in origin, though transformed by selection.

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HE EFFECT OF THE ORIENTATION OF CULTCH MATERIAL ON THE SETTING OF THE SYDNEY ROCK OYSTER

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Summary

In 1945-46 in Port Hacking, N.S.W. there was some spawning over the entire year, but successful spat-falls occurred only over the summer, with the greatest number in November and again in March.

On every 12-in. length of fibro-cement slat approximately 24 oyster spat were present (on all faces) 12 months after the slats were set out. Thus on the average a four foot slat carried 96 oysters or approximately four oysters every five square inches of surface.

A greater number of oysters settled when the slats were less than half an inch apart than when the slats were an inch apart. When the slats were one inch apart the central portion of the slats carried more oysters than the ends, but when the slats were within half an inch of each other the numbers at the ends and on the middle section were about the same. When the slats are within half an inch those oriented with the long axes parallel with the current show greater catches than those perpendicular to the current. However, when the slats are further apart the reverse is the case.

The horizontal portion of the broad surface supplies the highest catches, but the catch is more evenly distributed when they are vertical, and this would permit better growth. The ratio of the catches on upper horizontal, lower horizontal, and vertical surfaces is similar to the ratio found by Schaeffer for *O. gigas,* which is a similar type oyster to O. *commercialis.*

There is a horizontal gradient on the vertical surface across the batteries such that the number of oysters on the surface facing a particular direction increases on the columns more remote from that direction.

There is a vertical gradient on the vertical and upper surfaces such that the number of oysters caught increases on the lower rows of vertical surfaces, but the evidence is anomalous for the horizontal surfaces.

The discussion of the possible factors causing the pattern of set reveals that the reaction to light could be an explanation. But there are other explanations which are equally valid, and the experimental design was not such as to reveal the true causes.

The practice in Australia of using closely bundled cultch material is a good one; but there is a possibility that better total catches would ensue if the cultch set out in spring were removed to growing areas in January and new cultch set out to catch the autumn spat fall.

I. INTRODUCTION

The practice in the Australian oyster industry of using as cultch material ndles of sticks has raised several interesting problems. Firstly, there is the estion of the effective penetration of oyster larvae into these bundles, together with consideration of the intensity of setting according to position within th bundle. Secondly, there is the problem of determining the effect on this proces of various factors which work in other parts of the world has indicated may b operative in determining the effective nature of the set.

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The field experiments described herein were designed to reveal the pattern of the distribution of oyster spat within concentrations of more or less closely set cultch material. A complete assessment of the factors operating to provide such a pattern is impossible on the data.

Korringa (1940) has observed that counts on the spat at a late stage are not necessarily the same as the actual numbers of spat which originally set. Differential mortality rates may alter the proportions surviving on different surfaces. However, it should be noted that he does not back this assertion by data. Owing to lack of assistant staff and direction of the author's attention to other problems, it was impossible to conduct regular investigations at the time of setting.

In any case, it is not the primary set but the effective set that is important under normal cultivation conditions. The effective set may be defined as that portion of the primary set which survives to be set out to grow under normal cultivation practice. The initial (or primary) set and the subsequent differential mortality are purely biological problems which could not be studied under the circumstances.

II. METHODS

(*a*) *Experimental Design*

The Division's experimental spatting lease at the Ballast Heap, Port Hacking was used for the observations. This is an intertidal area where the mud flat rises abruptly from the channel and continues for some half-mile on a fairly constant level to the shore.

To eliminate any effect owing to fortuitous choice of position, three groups of cultch were used, one near the edge of the channel, one some 20 yards inshore and one some 25 yards further in again. The levels of the three groups were almost identical.

To obtain a substrate whose orientation could be accurately defined and which would be uniform both in dimensions and in the consistency of the physical and chemical properties, fibro-cement slats with plane surfaces were used as the cultch material. These slats are already used to a small extent industrially. Each slat was 4 ft. long and 1 in. wide, and a quarter of an inch deep.

In each of the three groups of cultch material, eight batteries of fibro-cement slats were set out. Of these, four batteries were set with the long axes of the slats east and west (hereafter termed E.-W.), and four with axes north and south (hereafter termed N.-S.). These correspond respectively to directions parallel to and perpendicular to the flow of the tidal current.

In each set of four batteries two were laid with the slats on edge (i.e. with he broad 1-in. face vertical) and two with the slats flat (i.e. with the broad -in. face horizontal). In each of these pairs of batteries, one had the slats et 1 in. apart; the other had the slats less than half an inch apart. Each attery consisted of 25 slats, set in rows of five and columns of five.

Each battery rested upon a foundation of a pair of parallel timber racks. hese supported the lowermost row of slats at about 3 inches from the ends. t this distance each slat had a round hole, ⅛ in. in diameter, bored through it. hrough these, round wooden divots were forced to hold the slats in place. hese passed vertically on batteries 3, 4, 7, and 8, and horizontally on batteries , 2, 5, and 6. By this means the area of surface required for support was kept o a minimum and access of water into the batteries was permitted as freely s possible. The lowest rows of the batteries were raised 18 in. above the mud nd slightly below mid-tide level.

TABLE 1

SUMMARY OF THE ARRANGEMENT OF BATTERIES

Group I (edge of channel)	Group II (20 yds. from channel)	Group III (45 yds. from channel)
E.–W. on edge 1 in. apart	ditto	ditto
E.–W. on edge ½ " "		
E.–W. on flat 1 " "		
E.–W. on flat ½ " "		
N.–S. on edge 1 " "		
N.–S. on edge ½ " "		
N.–S. on flat 1 " "		
N.–S. on flat ½ " "		

These groups of slats were set out in October 1945 at the beginning of the 45-46 spatting season, and were lifted approximately a year later, that is, the time when they would normally have been moved for depoting and setting t according to normal cultivation practices.

Over the same spawning period fibro-cement plates, whose surfaces were in. square, and which were set vertically in a frame, were regularly inspected determine the time of maximum spat-fall. These plates were on the same eas as the batteries, being between Groups II and III in distance from the annel.

(*b*) *Assessment of Results*

When the slats were moved, counts were made on the spatting lease to viate any likelihood of loss during transport. Two 6-in. sections were nted on each surface of each slat. One 6-in. section was taken at one end, d the other in the middle of the slat.

There is not necessarily a straight-line gradient of set between the ends and centres of the slats, but the constant method of counting validates comparison ween batteries. The method also permits examination of any differences in between the end and central portions of the slats.

Unfortunately for the uniformity of the records, the spatting grounds is of essity removed from constant surveillance and some damage, apparently by pleasure craft, was caused to some of the batteries. Consequently, when the final count was taken some batteries contained less than the original 25 slats. Therefore the result here had in some cases to be tabulated in the form of means rather than the simpler method of comparing the totals for the batteries. This accident to the field experiment does not affect the results as the same trends are apparent in both the batteries with a full complement of slats and those with fewer, and correlation between the damaged batteries and variation in catch (cf. Tables 2 and 4) is not apparent.

TABLE 2

NUMBER OF SLATS REMAINING IN EACH BATTERY AFTER 12 MONTHS

Battery Number (as in Table 1)	Group I	Group II	Group III
1	20	20	20
2	25	25	25
3	23	20	18
4	21	25	20
5	0	20	20
6	20	25	25
7	0	20	18
8	25	25	25

III. RESULTS

(*a*) *Duration of Spat-fall*

Spawning and setting occur to some extent over most of the summer months. Indeed, occasional larvae can be detected in the plankton even in winter, but apparently these do not survive to the setting stage.

TABLE 3

SPAT-FALL AT THE BALLAST HEAP, PORT HACKING, 1945-46

Date Inspected	Period of Set (days)	Set per Plate
31. x.45	14	14
14. xi.45	14	32
29. xi.45	15	36
12.xii.45	13	8
28.xii.45	16	0
10. i.46	13	0
25. i.46	15	40
8. ii.46	14	32
22. ii.46	14	24
16. iii.46	22	176
30. iii.46	14	8
13. iv.46	14	8
27. iv.46	14	0
13. v.46	16	0
No further spat (monthly inspection) until		
23. x.46	31	5

There thus appears to be a peak set in early November and another in March. The spat-fall in Port Hacking is the result of a number of sets rather than one peak setting. As a result, all the oysters obtained in cultch from this area are not strictly speaking of the same age, as setting occurred over a six months period.

That this is the normal period of setting is borne out by evidence of the Division's section on fouling investigations, during 1946-48. Their fouling plates, set at the mouth of Port Hacking (where the spat fall is only slight) caught oyster spat during November and December, and then again from February to May. Similar results were obtained at The Spit, Middle Harbour, Port Jackson, some few miles north of Port Hacking. In this case also a definite peak settlement occurred during March.

This long drawn spatting season suggests that the system of spat prediction which has been instituted in some places (J. Nelson 1907; T. C. Nelson 1917; Prytherch 1934; Korringa 1940; Borde 1929, 1937) would not be suitable in Australia.

(*b*) *Influence of the Collectors*

(i) *Amount of Set.*—The mean number of spat per 12 inches of slat was approximately twenty-four (Table 4). Assuming an even distribution on a 4-ft. slat there would be 96 oysters, or about four oysters to every 5 square inches of surface. This is a mean figure, the spat on any particular 12 inches varying from nil to twenty for 5 square inches. However, the catch was somewhat variable depending upon the orientation of the batteries of slats and upon the situation of the group.

If batteries 5 and 7 in Groups II and III are ignored in order to compare them more accurately with Group I, the weighted means become 26·3 and 21·4 respectively, which is very little different. The catch at Group III is significantly lower than at Groups I and II (Standard error of the difference of the means is 0·401 for Groups I and III and 0·299 for Groups II and III)

TABLE 4

CATCH OF OYSTER SPAT ACCORDING TO GROUPS AND BATTERIES (MEAN NUMBER PER 12 IN. OF SLAT)

Battery Number (as in Table 1)	Group I	Group II	Group III	Mean	
1	26·9	20·3	10·8	19·3	Mean E.–W. 24·7
2	30·2	26·5	23·4	26·7	
3	21·7	24·0	16·2	20·6	
4	31·3	32·1	29·2	30·8	
5		25·3	15·0	20·0	Mean N.–S. 23·5
6	19·6	28·1	22·8	23·9	
7		26·5	18·9	22·7	
8	30·4	27·1	26·0	27·8	
Weighted mean	27·6	26·4	20·7	24·2	

It is in those batteries where the slats are 1 in. apart (1, 3, 5, and 7) that Group III differs markedly from the others, but why this should be is not apparent. The only possible explanation seems to be that Group III was in the path of a current swirl and that those batteries with relatively large spaces between slats failed to provide sufficient slack-water for successful settlement.

Yokota (1936), quoted by Korringa, showed experimentally that larvae of *O. gigas* could not maintain their positions on cultch material in strong currents.

(ii) *Proximity of the Slats.*—It is evident from Table 4 that more oysters set on those batteries where the slats were less than half an inch apart (2, 4, 6, and 8) than on those where the slats were 1 in. apart.

(iii) *Position of Slats.*—Counts on the spat occurring on sections at the end and in the middle of slats (Table 5) reveal that the middle sections hold more oysters than the ends. Bonnot (1937) obtained contrary results within his batteries. But in the present case it can be seen that the effect was produced principally in those batteries where the slats were 1 inch apart (1, 3, 5, and 7), little difference was apparent in those batteries where the slats were less than half an inch apart. Bonnot's collectors were three-quarters of an inch apart.

TABLE 5

COMPARISON OF SETS ON 6 INCH LENGTHS AT ENDS (*a*) AND MIDDLE (*b*) OF SLATS

Battery Number (as in Table 1)	Group I		Group II		Group III		All Groups	
	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)
1	10·3	16·6	9·7	10·6	3·4	7·4	7·8	11·5
3	8·0	13·6	11·2	12·8	7·3	8·8	8·9	11·9
5			10·8	14·5	6·2	8·8	8·5	11·6
7			11·1	15·5	9·2	9·7	10·2	12·7
2	15·9	14·4	13·8	12·7	10·7	12·8	13·9	13·1
4	16·2	15·1	18·2	13·9	14·4	15·7	15·7	15·1
6	8·8	10·8	13·1	15·0	12·0	10·8	11·5	12·3
8	13·8	16·6	13·4	13·7	12·6	13·4	13·2	14·2
Mean	12·7	14·9	12·8	13·6	9·7	11·0	11·4	13·2

The figures in Table 5 are means and express the general tendency of catch at the ends and the middle of the slats within each battery considered as a whole. Examination of individual slats reveals that it is not an invariable rule that the middle sections hold more than the ends. But such is the case on the majority of slats.

Invariably on each battery there are some slats where the end section bears a greater number of spat than the middle portion. But in the majority of cases the middle portion has the greater number. Thus, in Table 6, it can be seen that in 30 cases out of 44, the central portion holds more than the end, in 12 cases the end holds more and in 2 cases they are equal. Moreover, where the slats are close (batteries 2, 4, 6, and 8) the difference is not so great. But there are more obvious differences in catch where the slats are 1 in. apart. In this case in only three batteries the end portions exceed the central in the number of spat carried. There were two where the numbers were equal and 15 where the central portion bore the greater number. The 5 cases contrary to the general rule are underlined in Table 6. In one of these (Group II, battery I) the northern surfaces were irregular in their catch. The other four cases involved the top surfaces where the catch is always low and often irregular (*vide infra*).

(iv) *Orientation to the Tides.*—The weighted means of the catch for all batteries and all groups for those batteries set with the slats parallel with the current (E.-W.) is very little different from the batteries set with axes perpendicular to the current (N.-S.), but when similarly arranged batteries within each group are compared, some significant facts emerge.

TABLE 6

NUMBER OF SLATS PER BATTERY WHERE END (*a*) OR MIDDLE (*b*) SECTIONS OF SLAT BEAR GREATEST NUMBER OF SPAT ON 1-IN. EDGES

Battery Number	Group I				Group II				Group III				Surfaces Left and Right Columns
	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)	
1	4	12	5	12	9	8	7	8	3	8	2	4	N S
2	12	8	13	8	7	10	7	9	5	11	9	11	N S
3	5	17	4	10	5	14	3	3	2	13	4	1	B T
4	10	11	10	5	12	11	11	5	4	11	10	8	B T
5					0	8	2	12	1	8	2	8	E W
6	4	9	9	7	9	12	10	12	7	9	11	6	E W
7					5	15	4	4	5	10	4	2	B T
8	9	16	13	8	10	11	4	12	11	14	7	13	B T

N = north-facing surfaces
S = south-facing surfaces
B = bottom surfaces
T = top surfaces
E = east-facing surfaces
W = west-facing surfaces

Thus, if batteries 1 and 5, 2 and 6, 3 and 7, 4 and 8, are compared, we find that battery (1) bears fewer spat than (5); battery (3) bears fewer spat than (7); battery (2) bears more spat than (6) (except in Group II) and battery (4) bears more than (8).

TABLE 7

—	Vertical		Horizontal	
	E.–W. Set	W.–S. Set	E.–W. Set	W.–S. Set
½-in. interspace	27·2	20·0	25·1	22·5
1-in. interspace	19·5	15·7	17·8	20·7

Thus, in those cases where the slats are 1 in. apart, the slats set parallel with the current (E.-W.) hold fewer spat than the comparable batteries set cross the current. But where the slats are only ½ in. apart, the slats set parallel o the current hold more spat.

This holds for both horizontal and vertical surfaces oriented in all directions Tables 7, 13, and 14).

Hopkins (1935, 1937), Schaeffer (1937), and Korringa (1940) obtained imilar results with vertical faces.

(v) *Orientation to the Horizontal.*—On the slats used as cultch material, he broad 1-in. faces provided the majority of the surfaces available for settling.

Examination reveals that in general there is a better fall on those slats with the broad surface horizontal. (Table 8). But the difference is not very great. Much more marked differences with the advantage to the horizontal surfaces have been found by Cole and Knight Jones (1939) and by Korringa (1940) for *O. edulis*; by Hopkins (1935) for *O. lurida,* and by Schaeffer (1937) for *O. gigas*

(vi) *Surface Differences.*—The difference between the sets on differently oriented slats is due to the far heavier catch on the lower surfaces, as is shown in Table 9.

TABLE 8

SET ON SLATS WITH BROAD FACES PERPENDICULAR (*a*) AND HORIZONTAL (*b*) (MEAN NUMBER PER 12-IN. LENGTH)

Battery Number (as in Table 1)	Group I	Group II	Group III	Mean	
(*a*) 1	26·9	20·3	10·8	19·3	22·9
2	30·2	26·5	23·4	26·7	
5		25·3	15·0	20·0	
6	19·6	28·1	22·8	23·7	
(*b*) 3	21·7	24·0	16·2	20·6	26·2
4	31·3	32·1	29·2	30·8	
7		26·5	18·9	22·7	
8	30·4	27·1	26·0	27·8	

Although the horizontal position provides a slightly greater total catch, the catch when the broad faces are vertical is much more evenly distributed. This would permit better growth than the crowded conditions of the under side of the horizontal slats.

Korringa (1940) has commented on the varying results obtained by different workers on the catch of variously inclined surfaces. Using Hopkins' (1937) notation of 0, 90, and 180° to symbolize the lower horizontal, vertical, and upper horizontal surfaces respectively, the various findings are summarized in Table 10.

TABLE 9

CATCH ON HORIZONTAL AND VERTICAL SURFACES (NUMBER OF SPAT PER 12 IN.) (ALL GROUPS)

Surface	Broad Face	
	Vertical	Horizontal
Bottom	4·8	21·0
Top	1·1	3·0
E. and N. sides	8·7	1·0
W. and S. sides	9·3	1·2

It is interesting to note the close similarity between the results of *O. gigas* and *O. commercialis* as these are both non-incubatory “ cup oyster ” types, whilst *O. lurida* and *O. edulis* are incubatory larviparous “ flat oyster ” types (known in

Australia respectively as "rock" and "mud" oyster types).

Despite the agreement between Hopkins' finding for *O. lurida* and that of Cole and Knight Jones for *O. edulis* that the bottom surfaces caught more than the top, Korringa (1940) is inclined to ignore the latter result as it was obtained in tanks where normal currents did not exist. In considering his own result that the upper surface caught the greater number, Korringa did not review one possibility, namely, the influence that the shape and construction of the containers he used would have on the currents passing through them.

TABLE 10

RATIO OF SPAT CATCH ON TOP (180°), BOTTOM (0°), AND SIDE (90°) SURFACES

Source Species	Hopkins (1935) *O. lurida*	Cole and Knight Jones (1939) *O. edulis*	Korringa (1940) *O. edulis*		Schaeffer (1937) *O. gigas*	Port Hacking, N.S.W. *O. commercialis*
			1938	1939		
0°	109	109	1·4	2	10	2·5
90°	1	1	1	1	1	1
180°	0·1	2	11	·5	0·2	0·4

If the suggestion that orientation of the larvae in the water has some nfluence on the nature of set is correct, then current swirls would upset the ormal orientation.

From the photographs of the apparatus used in the experiments (Figs. 18 nd 19 in Korringa (1940)) it would appear quite possible that abnormal current wirls would be set up in the apparatus shown in Figure 18 by the ose juxtaposition of the vertical and horizontal plates, and in the apparatus hown in Fig. 19 by the ripple set up as the current passed over the only row f openings to the inclined plates. The fan-shaped apparatus which he mentions ould also have the same rippling effect if the current passed over the plates right angles to their long axes.

Hopkins (1935, 1937) using apparatus somewhat similar to the first of these ree (though not constructionally identical) found for *O. lurida* that the catch lower surfaces outnumbered that on the upper surfaces.

However, Bonnot (1937) working on this same oyster, but a different type collector, obtained contrary results, securing a heavier catch on the upper rfaces. He further showed that, left for a longer time, differential mortality parently occurred, and the upper surface numbers fell below those of the wer surface. However, this cannot be the explanation for Hopkins' results, he left his plates out for only 24 hours.

From the confusion of results with the same oysters, it would appear that ry probably the exact construction of the apparatus concerned has a definite bearing on the results obtained. To compare results in different places identical apparatuses would be necessary. Identical inclination of plates or surfaces does not seem sufficient, as the apparatus supporting the plates in itself affects the direction and nature of the current passing to the collecting surfaces. Another precaution must be to provide equivalent lighting on the surface, as the illumination is generally believed to influence setting.

(vii) *Horizontal Gradient.*—So far the batteries have been treated as a unit in assessing variation in the intensity of set. There is, however, a gradient across the batteries in certain directions. Thus, counts made by columns across the batteries are shown in Tables 11 and 12. Although these tables show the means for all batteries, each battery considered separately shows results of the same order. The necessity for economy of space prevents presentation of the full results.

TABLE 11

INTENSITY OF SET, GRADIENT E.-W. ON N.-S. SET SLATS (MEAN CATCH PER 12 IN.) ALL BATTERIES

Column E.	1	2	3	4	5 W.
Surface—					
Bottom	11·2	15·1	15·5	12·8	12·9
Top	1·3	1·5	1·1	1·8	1·8
E. side	0·8	3·5	4·0	7·2	6·8
W. side	7·4	6·7	5·1	3·7	1·4
All sides	20·7	26·8	25·7	25·5	23·4

TABLE 12

INTENSITY OF SET, GRADIENT N.-S. ON E.-W. SET SLATS (MEAN CATCH PER 12 IN.) ALL BATTERIES

Column N.	1	2	3	4	5 S.
Surface—					
Bottom	11·6	12·4	14·1	12·4	12·9
Top	1·4	1·5	1·9	3·5	1·6
N. side	1·5	3·8	5·5	6·8	8·0
S. side	8·4	6·9	6·4	5·4	2·3
All sides	22·9	24·7	27·9	26·8	24·9

Among those on the under sides there is a slight increase in intensity of set towards the central columns. But the interesting finding is the gradient shown by the catch on the vertical faces. In each case the catch on the surface facing in a particular direction increases as the distance from the edge of the battery in that direction increases. Thus, those on the east side of the N.-S. laid slats increase in intensity of set from the east to the west sides of the battery. And similarly with the other surfaces. The regularity of each gradient is such that the total number of oysters on the two sides in any column is of the same general order as for any other column, and the total number of oysters on a particular verticle surface throughout a row is of the same general order as the total number on the other vertical surface.

This phenomenon is equally apparent in each row as well as in the atteries considered as a whole.

The gradient climbs more rapidly and the intensity of set is greater where he slats are less than ½ in. apart than when they are 1 in. apart (Tables 13 nd 14).

It is also evident on studying Tables 13 and 14 that whereas the mean ntensity of set is approximately the same for all the batteries with 1-in. spaces, n the ½-in. spaced batteries there is a greater amount of spat on the slats laid E.-W. than on those laid N.-S. From this it would appear that if the slats re set quite close together there is some advantage, as far as the vertical urfaces are concerned, in having the slats parallel with the tide. (But see iscussion below.)

TABLE 13

HORIZONTAL GRADIENT ON E.-W. SET SLATS
(MEAN CATCH PER 12 IN.) ALL BATTERIES

Side Column N.	Distance (in.)	1	2	3	4	5	S. Mean
N.	½	2·2	9·6	13·5	16·2	18·6	12·2
Side	1	3·9	4·7	7·0	9·9	11·1	7·3
S.	½	22·3	17·3	15·3	14·1	6·7	15·1
Side	1	11·0	8·9	8·7	6·6	1·1	7·2

TABLE 14

HORIZONTAL GRADIENT N.-S. SET SLATS
(MEAN CATCH PER 12 IN.) ALL BATTERIES

Side Column E.	Distance (in.)	1	2	3	4	5	W. Mean
E.	½	2·1	9·0	8·7	13·7	12·3	9·1
Side	1	0·5	2·6	6·4	14·5	14·4	7·5
W.	½	17·1	13·8	10·4	8·4	4·8	10·9
Side	1	10·8	12·0	12·3	4·8	1·4	8·2

(viii) *Vertical Gradient.*—When the distribution of the catch from top to ttom of the batteries is considered, differences are apparent according to the rface concerned. (Tables 15 and 16.)

Thus, while the intensity of catch on the bottom surfaces is greatest in the ntre rows, declining above and below, the vertical and upper surfaces show an creased catch on the lower rows.

Certain of the batteries (Table 2) had only 4 rows of slats. These gave a milar gradient of catch (Table 17).

Tables 15, 16, and 17 reveal that the uppermost row of any battery always s a catch appreciably smaller than the others.

The bottom layer is not very much affected by its being on one boundary of the group, though the catch on the lower side is somewhat lower on the bottom than on the central row. This result differs from that of Bonnot (1937) for *O. lurida,* where the bottom surface of the lowermost slat caught no spat. It is interesting that Korringa (1940) found that greater numbers set on the lower plates of his experiments. But in that case the plates which he used were considerably further apart than the slats used in this experiment. Moreover, Korringa's experiment was designed to test the intensity of set from surface to bottom, whereas the batteries of fibrocement slats described here were set within the limits usually used for catching by Australian oyster-farmers, namely, over about two feet approximately at mid-tide mark.

TABLE 15

VERTICAL GRADIENT OVER 5 ROWS ON E.–W. SET SLATS (MEAN CATCH PER 12 IN.)

—	Surface				Total
	Bottom	Top	N. Side	S. Side	
T row a	10·9	1·0	1·5	2·4	15·8
,, b	14·2	1·8	6·0	5·1	27·1
,, c	15·7	2·0	4·8	7·6	30·1
,, d	13·0	1·7	6·5	6·5	27·7
B ,, e	7·5	2·8	7·6	9·9	27·8

TABLE 16

VERTICAL GRADIENT OVER 5 ROWS ON N.– S. SET SLATS (MEAN CATCH PER 12 IN.)

—	Surface				Total
	Bottom	Top	E. Side	W. Side	
T row a	11·8	0·5	3·1	2·0	17·4
,, b	14·8	1·6	3·9	3·8	24·1
,, c	13·6	1·3	5·1	5·5	27·5
,, d	14·5	1·4	6·3	5·6	27·8
B ,, e	11·4	3·7	8·3	5·6	29·0

IV. DISCUSSION

The previous sections have described the experimental results. There follows a discussion on the possible factors influencing the pattern of spat distribution.

(a) *Negative Phototropism*

The factor which has been stressed above all others in explaining the phenomena attending oyster set is light. The evidence that larval oysters are negatively phototropic at the time of setting is inconclusive. The fact that ost workers have found more spat on the lower (and thus more shaded) rfaces of cultch material is the evidence usually adduced. But it has been inted out that the fact that the larvae settle in greater numbers on under rfaces may be attributable to the orientation of the larvae in the water Iopkins 1937). Also Korringa (1940) states that in the *O. edulis* in the osterschelde, the upper surfaces catch more spat than the lower, and Bonnot 937) reports similarly for *O. lurida.*

Some experimental evidence shows that oyster larvae are not negatively ototropic to light (Yokota 1936; Hopkins 1935, 1937; Prytherch 1934). hers have presented some evidence in support of the theory (Nelson 1926, 34; Cole and Knight Jones 1939).

From the evidence of the batteries used in the experiment reported here, me facts may be interpreted as indicating the influence of light. Thus, there e more oysters in the slats which are less than ½-in. apart than those which e 1 in. apart (Section III (*b*) (ii)).

TABLE 17

VERTICAL GRADIENT OVER 4 ROWS, E.–W. AND N.– S. SET BATTERIES COMBINED (MEAN CATCH PER 12 IN.)

—	Surface			Total
	Bottom	Top	Vertical	
T row a	9·9	0·7	4·9	15·5
,, b	13·9	1·3	6·5	21·7
,, c	15·3	0·9	8·3	24·2
B ,, d	11·7	1·8	8·2	21·7

Where the slats are closer, less light should penetrate. The mid sections of slats bear more spat than the ends; and the difference is more marked in the ts which are 1 in. apart (Section III (*b*) (iii)). This could be interpreted indicate that where the slats are less than ½ in. apart, the light intensity netrating to the end sections is not so great as where the slats are wider rt. Batteries with the slats set E.-W. and ½ in. apart, have more spat than ilar batteries set N.– S. (Section III (*b*) (iv)). The light is most intense en the sun is in the north so that slats perpendicular to the N.–S. direction uld provide more shade than those whose long axes are parallel with the S. line. However, in the batteries of 1-in. space between slats, the N.– S. slats bear more oysters than the E.– W., and this would be contrary to the ory, unless it so happens that the 1-in. space is enough for sufficient light to etrate to prevent any great amount of shade, and some other factor becomes rative. Also this explanation would hold only if the direct light from the is supposed to be more important in influencing the set than the diffused it from the sky, which is almost uniform from all directions. It is possible, ourse, that a slight differential intensity is sufficient to influence behaviour no absolute level of intensity is necessary.

More spat accumulates on the bottom of slats than on the vertical surface and least of all on the upper surfaces (Tables 9 and 10). These are in order o increasing openness to illumination.

The horizontal gradient on vertical faces across the batteries (Tables 1 and 12) is explicable, assuming a diminishing intensity of illumination fallin on the surfaces facing in a particular direction as distance from the edge i that direction increases. This presupposes also that the horizontal componen of light in the water is of sufficient intensity to influence the set. If ligh played a part we should expect an increase of spat fall from top to bottom o the batteries. Such a gradient is found in the vertical faces (Tables 15, 16 and 17), but the horizontal faces which would be expected to show still bettei gradation reveal irregularities. Thus, for the lower surfaces there is an increase i the number of spat from the top to centre rows, the number then declining t the bottom rows. Possibly there is light reflected up from the bottom, but thi should also affect the vertical surfaces. The top surfaces, however, would b protected from any light reflected from the substrate. In the top surface ther is also a gradation from the top row to the centre and then a peculiar drop o the second bottom row in those batteries whose slats are less than ½ in. apart Also, in batteries of slats 1 in. apart, there is some irregularity.

TABLE 18

NUMBER OF SPAT PER 3-FT. UPPER SURFACES OF SLATS

Group	Battery 4			Battery 8			Battery 3			Battery 7		
	I.	II.	III.	I.	II.	III.	I.	II.	III.	I.	II.	III.
Row a	0	0	30	19	6	3	14	0	9		0	0
,, b	19	22	26	20	15	22	33	0	+ 0		6	12
,, c	30	36	19	21	8	29	11	2	9		10	1
,, d	32	6	40	17	19	17	14	8	2		5	8
,, e	36	28		30	13	30	+ 9					

(*b*) *Other Factors*

All the phenomena mentioned above could be explained as reactions light, but there are alternative explanations for all of them.

(i) Current Force.—The most important of these is the influence of th current. Several studies (Yokota 1936; Nelson 1921; and Prytherch 1929) hav shown that oyster larvae require at least relatively slack water for settin Thus the fact that more oysters settle on slats relatively close together may b because the interior of such batteries is more sheltered and provides more slac water than the open batteries. Similarly, the central portions of the sla would be in contact with less turbulent water than the ends.

Likewise the horizontal gradient on the vertical faces might be due to th declining turbulence of the water as the distance from a particular edge of th battery increases.

(ii) Time of Immersion.—The fact that at least on some surfaces the low rows hold more oysters than the upper rows might be due to the longer perio of immersion of the lower rows as the tides rise and fall, but this also fails erpret the anomalous evidence of the horizontal surface.

(iii) Orientation to the Current.—Batteries with slats ½ in. apart and set -W. are parallel to the current direction, and this may be why more spat ttle on such batteries than on the N.–S. batteries. Those parallel with the rrent will have more water passing over the surfaces than the N.–S. set slats, ich will provide some opposition to the water flowing.

(iv) Silt and Slime.—The fact that the upper surfaces have such low ches could be interpreted as a result of the settlement of silt as oyster larvae l not settle on dirty cultch. The presence of slime (algae) on the sides facing light would also prevent spat settling. In this latter case the failure to set uld be an indirect effect of the light.

(*c*) *Conclusion*

Finally, it must be realized that what is observed is likely to be the mulative effect of several factors and that one factor alone is not necessarily limiting factor.

The experiments have shown a certain pattern in the settlement of the at, but do not reveal the explanation. Careful observations at or within 24 urs of the time of set are necessary to reveal the influencing factors. Control er the light reaching the batteries is a prime requisite as otherwise the light tor could conceivably interfere with an experiment designed to test the effect any other factor.

V. BEARING ON PRESENT SPAT-COLLECTING METHODS

It has been the practice in the Australian oyster industry to leave the tch material at the catching area for nearly 12 months. The long period er which the set occurs (Table 3) would seem to support this practice, but re is some evidence that an alteration in practice would provide greater spat ches. The spat catch is clearly divisible into early summer and autumn ases. The spat fall over the whole period amounts to a catch of 13 oysters 5 square inches. As revealed by the slats which were left undisturbed for months, the catch was only four per 5 square inches. Possibly, some of this erence is due to mortality over the period, but undoubtedly the catch of the ly summer months (three per 5 square inches) would, to a not inconsiderable ent, debar some of the later spat potential (ten per 5 square inches) from ling by occupying space and by cannibalism. Accumulation of silt and slime the cultch over the period would also diminish the catch potential of the face. The removal of the cultch material to growing beds in early January owed by the setting of more cultch material to harvest the autumn settlement ld result in an increased total catch.

In some instances where the distances to be travelled by the cultch from ting to growing beds are great, too many of the young spat might be royed by removal at so early a stage. But careful handling over short ances, especially in the same river system would be safe. The Japanese ılarly remove their cultch a month after the spat has been caught. It is ous that the present practice of many oyster men of setting cultch in close bundles in itself induces a better spat fall (Section III (*b*) (ii)), besides rding protection from marauding fish, such as bream and stingrays. The experiments also suggest that when using fibro-cement slats or other plane surfaced materials as cultch, a better catch is obtained if the individual pieces are set within ½ in. of each other. Also, although the bottom surfaces catch the greatest numbers of spat, the upper surfaces catch the least. Often the density on the lower surface is so great that a considerable proportion of the oysters will be smothered in the competition for growing space.

A more uniform catch of reasonable density is obtained from the vertical surfaces. Therefore, it can be recommended that the broadest surfaces of the cultch material should be set vertically.

Those batteries set closest to the channel caught more spat and they may indicate the desirability of concentrating cultch on the flats near the edge of channels rather than haphazardly anywhere on the flat as is often the case.

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THE TASMANIAN WHITEBAIT, *LOVETTIA SEALI* (JOHNSTON), AND THE WHITEBAIT FISHERY

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Summary

The biology of the aplochitonid *Lovettia seali* (Johnston), which comprises over 95 per cent. of the Tasmanian whitebait catch, has been studied. Over 78,000 fish from 95 samples were sexed and measured, and 1,200 were classified as to maturity, pigmentation stages, and the presence or absence of food in the stomach. Vertebra counts were made for 1,200 specimens, and there were other observations upon smaller amounts of material.

There are marked resemblances to other salmonoids in most points of the biology. There is conspicuous sexual dimorphism. The fish are anadromous and at their ascent are all mature or almost so, and all of the same age (one year by otoliths). After spawning begins there is progressive discoloration and emaciation, followed almost invariably by death. About 0.001 per cent. of the stock consists of two-year fish. The eggs are large compared with the size of fish (extremes of standard length in the adult stock are 33 and 70 mm.) and the incubation period is about three weeks. The larvae drift downstream to the sea. Sex ratio is highly variable, but generally the males greatly outnumber the females.

A northern and a southern population can be distinguished, the differences being in growth rate and pigmentation. Each population supports a separate fishery, which operates on the ascending shoals.

The history of the fisheries is outlined. The southern fishery has never been important because the fish available at the principal fishing locality are excessively pigmented. More suitable fish could be taken by operating further downstream, where the fish are typically at an earlier stage of maturity. The northern fishery has been vigorously prosecuted and overfishing was probably the cause of the decline in abundance of stock in 1947 and 1948. If there was overfishing, it operated purely by excessive removal of reproducers. The order of the optimum catch is empirically identified and a programme for the management of the stock, aiming at its rehabilitation, is recommended.

I. INTRODUCTION

The effective fishery for the Tasmanian whitebait, *Lovettia seali* (Johnston), dates from 1941. Previously small quantities were occasionally caught for home consumption or sale as fresh fish. When the Tasmanian fish canning industry began to develop in the late 1930's it faced difficulties in obtaining large and regular supplies. As whitebait were known to be abundant and easily caught in certain rivers, it was natural that they should attract the attention of the canners while the industry was in this phase. This was especially so because Australians had long been familiar with a superficially similar product, the canned

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whitebait (*Galaxias attenuatus*) of New Zealand. The whitebait fishery then grew rapidly in importance, the 1947 catch being about 1 million lb. It was more valuable to the canners than the actual size of the catch might suggest, because it was available at a time of year when other fish were scarce.

The Organization's Division of Fisheries first became interested in whitebait in 1942, mainly for the purpose of encouraging its exploitation. In 1944 and 1945 the Division was asked, first by a canning firm and later by the Tasmanian Fisheries Division, professional fishermen, and anglers, to study the fishery for possible conservation requirements. This work, together with a special study of colour variations which had also been asked for, was begun in 1945.

Before this work began, some observations were independently made by Professor V. V. Hickman, of the University of Tasmania, and Mr. A. V. G. Paddon, of Latrobe, Tasmania. These dealt mainly with the sexual dimorphism, which these workers were the first to recognize, fertilization, and hatching experiments. Professor Hickman and Mr. Paddon were good enough to make available notes and specimens which materially assisted the author's research. As these workers did not wish to publish their observations themselves it was agreed that they should be reported in this paper.

II. TAXONOMY

Order ISOSPONDYLI
Suborder SALMONOIDEI
Family APLOCHITONIDAE
Genus LOVETTIA McCulloch 1915
LOVETTIA SEALI (Johnston 1883)

Haplochiton sealii Johnston 1883, p. 128; Macleay 1884, p. 54; Johnston 1891, p. 36.
Lovettia seali, McCulloch 1915, pp. 259-61; Plate 35, Fig. 2; Lord 1923, p. 63; Lord and Scott 1924, p. 34; McCulloch 1929, p. 50; Scott 1936*b*, pp. 113-4.

Regan (1909, p. 82, and 1913, pp. 289-90) classified the family as shown above, and was followed in this by Jordan (1923, p. 125). Chapman (1944, p. 164) considered, from osteological characters, that the family should be placed in the order Haplomi. It is shown subsequently that the life history of this species is similar to that of various salmonoids, which makes the author incline to the views of Regan and Jordan. The family consists of three genera: *Aplochiton* Jenyns 1842, with *A. zebra* and *A. taeniata*, both from the southernmost regions of South America (including the Falklands); *Prototroctes* Günther 1864, with *P. maraena* from south-eastern Australia (including Tasmania) and *P. oxyrhynchus* from New Zealand; and *Lovettia*, with the single species studied here, from Tasmania only. *Aplochiton* and *Lovettia* are much alike: they have urinogenital papillae and no scales. In fact, McCulloch established *Lovettia* as a separate genus on rather flimsy grounds, although there is a very satisfactory distinction of which he was unaware. *Aplochiton* has the urinogenital papilla near the origin of the anal fin in both sexes (Günther 1864, p. 381), but in *Lovettia* this applies only to the female, the male organ being far anterior (see next section). *Prototroctes* has scales and no urinogenital papilla.

Lovettia seali was first described from the Derwent River (New Norfolk) and has been called "Derwent smelt" by some authors. However, it occurs in many other rivers, and the name "smelt" is generally retained for the members of a different salmonoid family, the Osmeridae. Since *Lovettia* constitutes over 95 per cent. of the fish collectively styled "whitebait" in Tasmania (Section XII), it is hereafter sometimes referred to by that name. References to "whitebait" signify *Lovettia* unless a wider meaning is specifically indicated.

III. SEXUAL DIMORPHISM

(*a*) *Urinogenital and Alimentary System*

These features were independently investigated by Professor V. V. Hickman and Mr. A. V. G. Paddon. It is now clear that the description by McCulloch (1915) is only that of the female. The notes and figures in this paper are based upon the author's own dissections, which confirmed and elaborated the findings of Hickman and Paddon.

The sexes can be distinguished externally by the position of the urinogenital papilla, which is in the mid-ventral line. In females this is situated a little anterior to the anal fin origin (see Plate 1). In males it is usually immediately behind the head, between the pectoral fins (see Plate 2), but occasionally it is more posterior, at various positions up to the pelvic girdle. The genital and urinary openings are on the papilla in each sex, and the anus also in the male; in the female the anus is not strictly on the papilla but just anterior to it on the abdomen. The male papilla is larger and of different shape (Fig. 1).

The alimentary system is very simple in both sexes. There are no pyloric caeca and the liver is unilobate. A large oval swim-bladder is present. The urinary system in both sexes consists of the paired kidney just posterior to the swim-bladder, and two closely approximated ureters (only one shown in Fig. 1) which unite at the urinary bladder just above the urinary opening.

The other main features of the viscera and their arrangement are different in the sexes. In the female the intestine and ureters run posteriorly to the end of the coelome. The mature ovaries extend almost the full length of the coelome, into the posterior end of which free ova are shed. The ova are then extruded through a single large genital pore which opens on to the papilla.

In the male the intestine is recurved so as to terminate at a point anterior to its commencement. The stomach is also slightly displaced. The ureters run anteriorly from the kidney, and so appear to be much longer than they are in the female; actually they probably are not, because they follow a wavy course in the female, although this is not shown in Figure 1. The testes are closed sacs from the posterior ends of which run, anteriorly, the vasa deferentia. These unite just above the genital opening. The posterior part of the coelome is virtually empty.

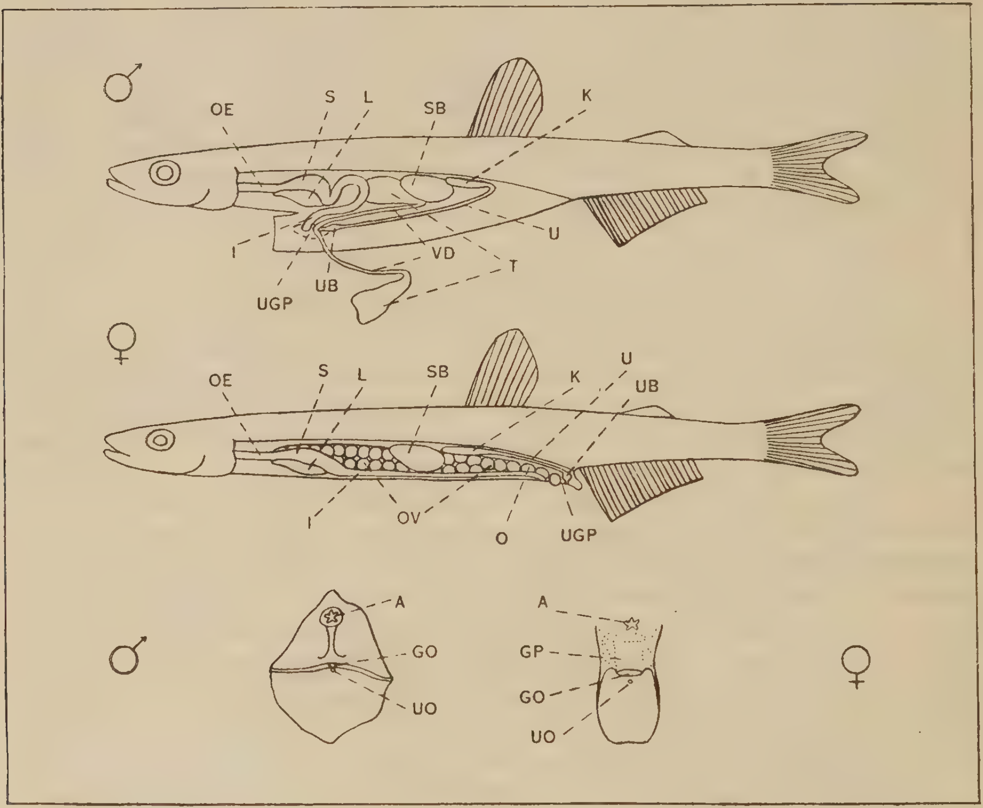


Fig. 1.—(Above.) Dissections of male and female *Lovettia seali*, semi-diagrammatic. Only one ureter is shown in each, and only the right ovary in the female. (Below.) Ventral views of male and female urinogenital papillae. A, anus; GO, genital opening; GP, genital pore; I, intestine; K, kidney; L, liver; O, ova free in coelome; OE, oesophagus; OV, ovary; S, stomach; SB, swim-bladder; T, testis; U, ureter; UB, urinary bladder; UGP, urinogenital papilla; UO, urinary opening; VD, vas deferens. For further explanation see text.

Apart from the fact that there is only one genital pore, the arrangement of the organs in the female is fairly typical of that in salmonoids. The arrangement in the male represents a remarkable departure from the usual condition: it is as if there was originally a posterior papilla (as in the female, although including the anus as well as the other openings) which moved anteriorly, dragging intestine, ureters and vasa deferentia with it. In the two species of *Aplochiton*, Jenyns (1842, pp. 132-3, Plate

24) described a papilla on which the alimentary and genital systems both terminated (there was no mention of a separate urinary opening, although this could easily have been overlooked), just anterior to the anal fin origin. Jenyns did not state that this was the condition in only one sex, and Günther (1864, p. 381) specifically remarked that it was so in both. This was doubtless close to the ancestral form of *Lovettia*. However, the whole metamorphosis still takes place in the ontogeny of *Lovettia* itself, because in the many hundreds of larvae examined the anus was always posterior (Section VI). The finding of occasional mature males with the papilla more posterior than usual, although always anterior to the pelvic girdle, is also significant. The relative alteration in position of the papilla must be largely effected before the formation of the pelvic girdle. Unfortunately, *Lovettia* has not been found at any stage between the young larva and the almost mature adult. Probably the last stage of the metamorphosis typically occurs just before the spawning run, because the specimens in which the papilla was more posterior were mostly filling or full, rarely part-spent, and never spent (see Section V).

(*b*) *Size of Pectoral Fin*

The pectorals are much larger in males than in females, as shown in Plates 1 and 2. In males the fin is as long as the head measured from the snout tip to the posterior margin of the operculum. In females it is only equal to the distance from the snout tip to the posterior margin of the eye. A similar sexual dimorphism, involving other fins as well, has been found in two osmerids (Hart and McHugh 1944, pp. 4, 21-2).

(*c*) *Number of Vertebrae*

The mean number of vertebrae is nearly always higher in males than in females, in samples of 50 or more of each sex. This is dealt with in Section X.

(*d*) *Remarks*

Sexually mature *Lovettia* occur in distinct shoals containing great numbers of closely congregated fish. Although one sex generally predominates in a shoal, considerable numbers of both are usually present (Section VIII). Parr (1931) believed that dense shoaling would not as a rule occur in species with conspicuous external sex differences. He thought the differences would evoke differential sex attractions which would cause shoals to break up quickly into heterosexual pairs or small groups. This hypothesis can hardly be sustained in view of the situation in *Lovettia* and in certain osmerids (Hart and McHugh 1944).

IV. REGIONAL AND SEASONAL DISTRIBUTION

Lovettia is known only from Tasmanian mainland waters. Whitebait have been reported from many such localities, but because of uncertainty about the species the author merely reports the distribution as established from specimens he has seen. These were taken:

(*a*) from a region extending almost the full length of the north coast, from the Duck River in the west to the New Great Forester River in the east; and

(*b*) from a region in the south-east extending from the Esperance River north to Blackman's Bay at Dunalley (Fig. 2).

There have been reports of whitebait from various rivers on the west coast, but none of any reliability from any part of the east coast north of Blackman's Bay.

There are two areas in which fishing is done, corresponding with the regions (*a*) and (*b*) above. All the north coast streams shown in Figure 2 have been fished, except possibly the Tamar. However, *Lovettia* occurs in the Tamar also (Scott 1936*b*, p. 113). In southern Tasmania the fishery is small, but commercial operations have been carried out in the Esperance, Huon, and Derwent Rivers, and in or around Norfolk Bay. The record of *Lovettia* at Blackman's Bay is based on fish captured during research operations.

The only stages in the life history of *Lovettia* so far observed are the mature adults, at the stage at which they ascend rivers in shoals to spawn, and the eggs and very young larvae, as found in streams at the same season. Some observers have stated that schools of whitebait occur a few miles out to sea, about a month before they commence to run in the rivers. These are probably *Lovettia,* as it is shown elsewhere that the species has a marine phase, but the author has not seen specimens. *Lovettia* is also said to have been found in the stomachs of barracouta (*Thyrsites atun*) and rock cod (*Physiculus barbatus*) taken at sea. The author found fresh *Lovettia* in the stomach of a barracouta taken in October, off Port Huon in the Huon estuary. The chlorinity of the water was 5.69 parts per thousand. Chlorinities in 23 water samples taken from the actual whitebait fishing localities in various rivers in 1945 and 1946 ranged from 0.02 to 1.18 parts per thousand, but the values for 17 of these were 0.10 or less. The analyses were made by the C.S.I.R.O. Division of Fisheries and the Tasmanian Government Analyst's Branch. From these results and from direct observation it appears that the fishing area in any river is situated at or above the uppermost reach of tidal influence. If there is any estuarine delta formation the fishery is in the delta or just above it (e.g. Mersey, Forth), and in one case some distance above it (Huon). The fishing locality in the Derwent (New Norfolk) is also relatively far upstream.

The season at which the fish are found in the rivers is broadly the spring, but differs in the north and south. Table 1 shows that the 53 northern whitebait samples received by the author were taken from early August to November in different years, but the two November samples (both Mersey River) contained very few *Lovettia,* being mostly juvenile *Galaxias truttaceus.* These were the only samples in which

Lovettia did not predominate. Statements from observers who could distinguish *Lovettia* and *Galaxias* indicate that the season for the latter is later (late September onwards, see also Scott 1941, p. 60-1); and that, as *Galaxias* is not prized by the canners and is not as freely available as *Lovettia*, little fishing is done for it (see also Section XII). The northern season for *Lovettia* can be said to cover broadly the three months August

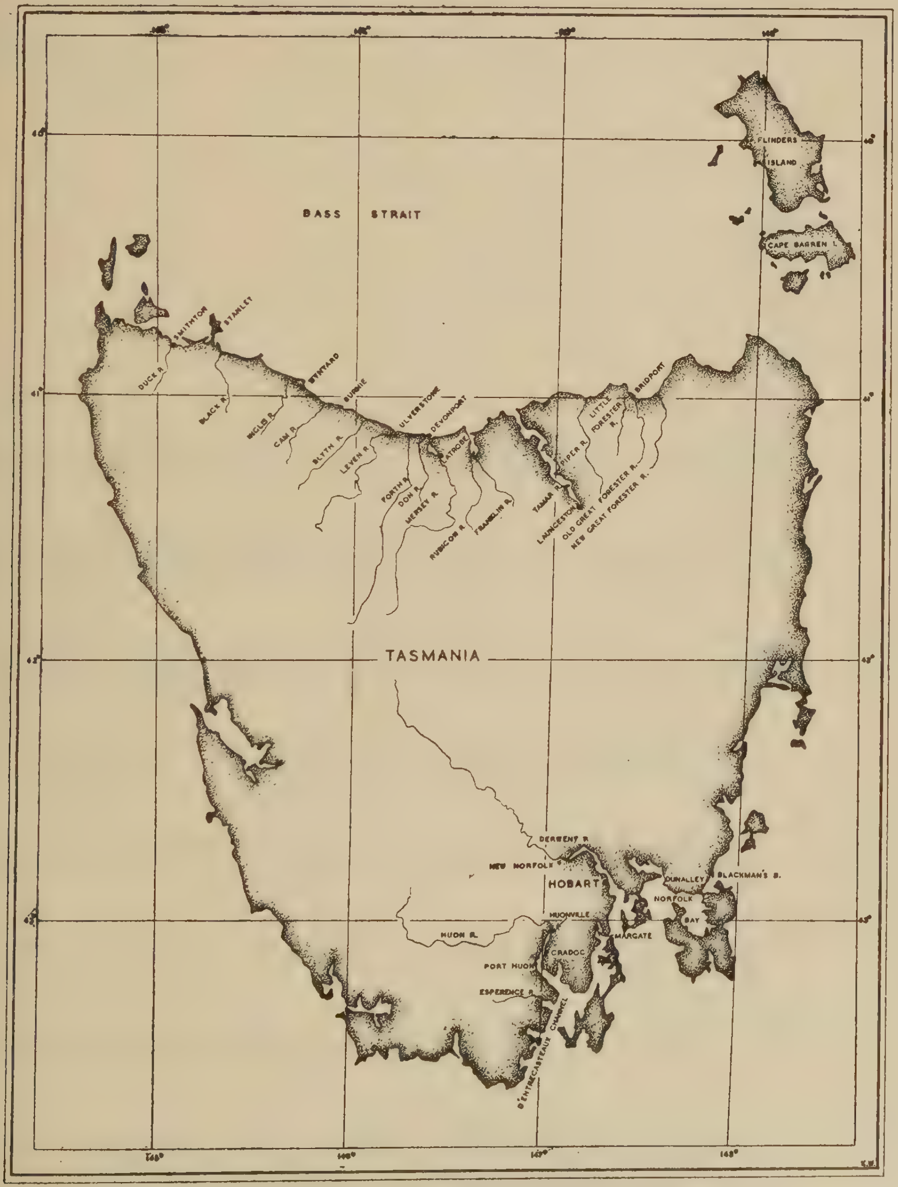

BASS STRAIT
FLINDERS ISLAND
CAPE BARREN I.
SMITHTON
STANLEY
DUCK R.
BLACK R.
WYNYARD
BURNIE
INGLIS R.
CAM R.
BLYTH R.
LEVEN R.
ULVERSTONE
DEVONPORT
LATROBE
FORTH R.
DON R.
MERSEY R.
RUBICON R.
FRANKLIN R.
TAMAR R.
PIPER R.
LITTLE FORESTER R.
BRIDPORT
LAUNCESTON
OLD GREAT FORESTER R.
NEW GREAT FORESTER R.
TASMANIA
DERWENT R.
NEW NORFOLK
HOBART
HUONVILLE
HUON R.
CRADOC
PORT HUON
ESPERANCE R.
D'ENTRECASTEAUX CHANNEL
MARGATE
DUNALLEY
BLACKMAN'S B.
NORFOLK BAY
145°
146°
147°
148°
40°
41°
42°
43°

Fig. 2.—Tasmania, showing localities mentioned in text.

TABLE 1

PARTICULARS OF WHITEBAIT SAMPLES FROM NORTHERN TASMANIA. LS SIGNIFIES LOVETTIA SEALI; GT, GALAXIAS TRUTTACEUS; GA, GALAXIAS ATTENUATUS; RT, RETROPINNA TASMANICA; TL, TASMANOGOBIUS LORDI; CT, CTENOGOBIUS TAMARENSIS; AT, ATHERINOSOMA TAMARENSIS. LENGTHS ARE STANDARD LENGTHS IN MM. MEAN LENGTH DIFFERENCE (DIFF.) IS MEAN LENGTH OF ♀ MINUS MEAN LENGTH OF ♂

		LS													
River	Date	Female	Male	Total No.	♂ per 100 ♀	Mean Length ♀	Mean Length ♂	Mean Length Diff.	No. GT	No. GA	No. RT	No. TL	No. CT	No. AT	Remarks
Duck	24. ix.45	249	549	798	220	45.71	43.71	2.00							
	29.viii.46	104	1302	1406	1252	47.04	44.09	2.95							
	12. ix.46	27	1861	1888	6893		44.18								
	24. ix.46	194	1966	2160	1013	46.54	42.49	4.05							
	Total	574	5678	6252	989										
Black	24. ix.45	62	402	464	648		45.52								
	29.viii.46	124	991	1115	799	47.31	44.83	2.48							
	12. ix.46	138	1255	1393	909	48.42	44.33	4.09							
	10. x.46	742	467	1209	63	44.94	40.90	4.04	1						
	Total	1066	3115	4181	292				1						
Inglis	4. ix.46	825	379	1204	46	47.45	43.94	3.51							
Cam	26. ix.45	189	710	899	377	45.02	42.81	2.21							
	4. ix.46	477	780	1257	164	48.45	45.05	3.40							
	Total	666	1490	2156	224										
Leven	18. ix.44	295	320	615	108	45.30	41.58	3.72	2						
	25. ix.44	227	631	858	278	45.83	42.70	3.13							
	29. ix.44	164	710	874	433	44.21	42.73	1.48							
	2. x.44	181	612	793	338	46.58	42.62	3.96							
	9. x.44	400	363	763	91	45.40	41.83	3.57							
	16. x.44	436	388	824	89	44.74	41.32	3.42	2						
	23. x.44	277	820	1097	296	44.80	41.99	2.81	56	2					
	30. x.44	191	634	825	332	47.46	42.68	4.74							
	21. ix.45	121	670	791	554	45.70	42.66	3.04	1						Upstream
	21. ix.45	270	194	464	72	44.94	42.19	2.75	4						Downstream
	24. ix.45	122	313	435	257	44.29	41.92	2.37							
	21.viii.46	64	669	733	1045		45.51								
	21.viii.46	111	664	775	598	49.54	45.91	3.63							

Leven	3. ix.46	243	1166	1409	480	47.32	44.07	3.25							
(*cont.*)	7. ix.46	414	455	869	110	47.24	43.33	3.91							
	7. ix.46	367	569	936	155	47.06	43.75	3.31							
	Total	3883	9178	13061	236				65	2					
Forth	16. ix.45	118	576	694	488	45.99	45.16	0.83	33	2					
	20. ix.45	223	634	857	284	45.38	43.47	1.91							
	23. ix.45	39	401	440	1028		43.88								3.20 p.m. } Same place
	23. ix.45	549	22	571	4	44.74									5.15 p.m. }
	26. ix.45	331	448	779	135	46.32	42.57	3.75							
	2. x.45	229	612	841	267	45.54	42.13	3.41							
	Total	1489	2693	4182	181				33	2					
Don	2. ix.46	674	446	1120	66	48.22	44.01	4.21							
	25. ix.46	399	938	1337	235	44.03	42.41	1.62							
	Total	1073	1384	2457	129										
Mersey	10. ix.42	124	218	342	176	52.89	49.01	3.88	17	1					
	7. ix.44	421	275	696	65	48.75	44.89	3.86							
	14. ix.44	442	261	703	59	45.78	43.96	1.82							
	21. xi.44	—	2	2	—				448	22					
	8.viii.45	35	424	459	1211		47.81								
	22. ix.45	393	121	514	31	46.16	43.92	2.24	7	6	1				
	20.viii.46	167	722	889	432	48.45	45.67	2.78							
	20.viii.46	368	793	1161	215	48.82	46.19	2.63							
	2. ix.46	513	662	1175	129	48.68	44.64	4.04							
	5. ix.46	443	826	969	119	47.53	43.50	4.03							
	5. ix.46	392	578	970	147	49.26	44.23	5.03							
	7. xi.46	9	21	30	—				342	3					
	Total	3307	4603	7910	139				814	32	1				
Rubicon	30.viii.46	381	389	770	102	44.67	41.30	3.37	30	6				1	
	1. ix.46	443	960	1403	217	48.06	44.49	3.57							
	17. ix.46	411	720	1131	175	45.99	42.32	3.67	2	1	5	17	3		
	10. x.46	557	640	1197	115	45.69	41.00	4.69	29	10	1		1		
	Total	1792	2709	4501	151				61	17	6	17	4	1	
Franklin	1. ix.46	137	1289	1426	941	49.02	44.43	4.59				13			
New Great Forester	7. ix.48	93	667	760	717		45.23								
Grand Total		14905	33185	48090	223				974	53	7	30	4	1	

TABLE 2

PARTICULARS OF WHITEBAIT SAMPLES FROM SOUTHERN TASMANIA, EXCLUDING II-GROUP LOVETTIA. LS SIGNIFIES LOVETTIA SEALI; GT, GALAXIAS TRUTTACEUS; GA, GALAXIAS ATTENUATUS; RT, RETROPINNA TASMANICA. LENGTHS ARE STANDARD LENGTHS IN MM. MEAN LENGTH DIFFERENCE (DIFF.) IS MEAN LENGTH OF ♀ MINUS MEAN LENGTH OF ♂

		LS										
River	Date	Female	Male	Total No.	♂ per 100 ♀	Mean Length ♀	Mean Length ♂	Mean Length Diff.	No. GT	No. GA	No. RT	Remarks
Derwent	8. x.44	308	594	902	193	43.57	42.50	1.07	5			
	1. x.45	145	846	991	582	43.97	43.85	0.12				
	16. xi.46	207	1003	1210	484	39.85	38.44	1.41	26	33		
	Total	660	2443	3103	370				31	33		
Huon	17. xi.42	156	525	681	336	40.99	39.86	1.13				
	4. xii.42	68	668	736	982		40.47				1	
	29. ix.44	160	832	992	520	43.58	44.62	–1.04				
	6. x.44	174	811	985	466	44.21	43.80	1.41	1			
	20. xi.44	345	616	961	179	44.51	42.23	2.28		4		
	17. ix.45	27	1162	1189	4304		44.51					
	20. ix.45	134	285	419	213	44.20	41.71	2.49			1	
	23. ix.45	26	521	547	2004		43.01					
	30. ix.45	28	372	400	1329		41.89					
	6. x.45	70	452	522	646		42.07					
	21. x.45	188	418	606	222	42.11	40.86	1.25				
	23. x.45	142	57	199	40	43.44						
	25. x.45	—	325	325	—		39.97					Night catch
	26. x.45	101	1405	1506	1391	41.58	40.99	0.59	1			Upstream
	26. x.45	266	124	390	47	41.04	40.26	0.78	3			↓
	26. x.45	182	49	231	27	42.37			11		10	Downstream. Cradoc
	29. x.45	34	385	419	1132		39.99		4			

TABLE 2 *(continued)*

		LS										
River	Date	Female	Male	Total No.	♂ per 100 ♀	Mean Length ♀	Mean Length ♂	Mean Length Diff.	No. GT	No. GA	No. RT	Remarks
Huon (contd.)	5. xi.45	132	279	411	211	41.80	40.26	1.54			2	
	7. xi.45	63	644	707	1022		40.05					
	10. xi.45	50	789	839	1578		39.96					
	13. xi.45	7	374	381	5343		40.46					
	17. xi.45	218	29	247	13	41.21						
	18. xi.45	151	596	747	395	41.28	39.27	2.01				Upstream
	18. xi.45	356	96	452	27	40.85				1		
	18. xi.45	682	57	739	8	41.22			2	4		↓
	18. xi.45	389	20	409	5	40.81				1		
	18. xi.45	247	14	261	6	41.33				3	3	Downstream
	25. xi.45	174	685	859	394	40.18	39.42	0.76			1	
	29. xi.45	53	301	354	568		39.57					
	2. xii.45	568	392	960	69	41.55	39.76	1.79				
	10. xii.45	788	514	1302	65	40.65	39.34	1.31				
	12. x.46	450	715	1165	159	40.82	41.10	–0.28	2			
	25. x.46	235	630	865	268	41.67	40.39	1.28	68	17		
	30. x.46	284	652	936	230	41.34	40.62	0.72	46	18		
	3. xi.46	324	596	920	184	41.11	40.54	0.57	64	17		
	7. xi.46	334	662	996	198	41.10	40.45	0.65	86	16		
	2. xii.46	449	447	896	100	42.05	40.70	1.35	6	8		
	11. xii.46	354	457	811	129	41.85	40.94	0.91	12	29		
	Total	8409	17956	26365	214				306	118	18	
Esperance	2. x.46	121	704	825	582	41.20	40.83	0.37				
Grand Total		9190	21103	30293	230				337	151	18	

to October. Occasionally whitebait are taken in the last days of July and these are probably *Lovettia*, but the author has not seen any.

In the south, judging from the dates of the 42 samples in Table 2, all of which were predominantly *Lovettia*, the season is also approximately three months, mid September to mid December. There are no records of catches at any earlier or later date, although shoals have been reported in the Huon in August. The only available figures which relate to the monthly dissection of a season's catch are those of Table 3, which give this information for that part of the 1948 catch reported by fishermen in their returns to the Tasmanian Fisheries Division (about 64 per cent. of the total catch of that season, cf. Table 12). The November catches in the north were probably mainly *Galaxias*. There were no December records from the south, probably owing to the poor demand for the fish of that area.

TABLE 3

MONTHLY DISSECTION OF THE PART OF THE 1948 WHITEBAIT CATCH REPORTED IN FISHERMEN'S RETURNS, FOR NORTHERN AND SOUTHERN AREAS, IN LB.

Month	North	South	Total Tasmania
July	1,200	—	1,200
August	69,840	—	69,840
September	85,501	10,075	95,576
October	37,905	11,176	49,081
November	7,043	1,520	8,563
Total	201,489	22,771	224,260

The whitebait season does not, however, appear to be quite the same in each northern river, and this may also apply in the south. In 1946, the first commercial catch was taken from the Mersey on August 17, the Leven and Rubicon on August 21, the Black on August 28, and the Forth on September 2. Fish were taken from the Duck on August 29, the Franklin on September 1, the Don on September 2, and the Cam and Inglis on September 4, but these were not the first catches in the two last-named at least. Thus fishing began within 17 days at all the principal centres west of the Tamar, and the order in which the streams began to yield was regarded as fairly typical by the fishermen and buyers; the Mersey and Forth are almost always first and last respectively, although they are closely adjacent. The commencement of the season east of the Tamar is usually about the beginning of September. The information of Table 3 dissected for individual streams (details not given) shows that the Rubicon, Mersey, Black, and Duck yielded more fish in August, and the Forester, Don, Forth, Leven, Blythe, Cam, and Inglis more in September, than in any other month. It is practically impossible to regard these observations as indicating differences in time of arrival of the fish in the various rivers from the sea, especially since there is only one population on the whole north coast (Section X); but they might be correlated with differences in precipitation over the individual watersheds and volume of flow downstream, which could be more or less constant from year to year. Floods definitely halt or greatly slow down the ascent of the whitebait.

V. MATURITY AND FECUNDITY

Four gonad maturity stages were recognizable in adult *Lovettia*. Although intergrading occasionally made it difficult to identify the stage for a particular fish, especially in males, the following criteria were found generally satisfactory:

Females

Filling.—Ovaries extending anteriorly to the stomach region but only about two-thirds filling the body cavity; with small, opaque white eggs (about 0.4 mm. diameter) only or with some large transparent eggs (about 1.1 mm. diameter) posteriorly, the latter usually colourless (occasionally yellow) and unshed.

Full.—Ovaries as long as in the preceding stage, but filling the body cavity, and consisting mainly of large transparent yellow eggs with some in process of being shed (i.e. free in the coelome or genital pore); occasionally the shed eggs were colourless.

Part-spent.—Ovaries as long as in the preceding stages, with a small number of large yellow eggs remaining anteriorly, and flaccid and almost empty posteriorly; or reduced to a short sac at the posterior end of the coelome, containing a few large yellow eggs in process of being shed.

Spent.—Ovaries small and flaccid, containing only a few well-separated, small, opaque eggs.

Males

Filling.—Testes about 5-6 mm. long and 2-3 mm. wide, opaque, cream-coloured rather than white. This was difficult to distinguish from the full stage, and was probably sometimes confused with it, although it did not seem to be very common.

Full.—Testes about 6-8 mm. long and 3 mm. wide, opaque white.

Part-spent.—Testes about 4-6 mm. long and 2 mm. wide, becoming flaccid, partly transparent.

Spent.—Testes 2-3 mm. long, flaccid, and transparent.

Maturity stages were recorded for 1200 fish, 50 of each sex for each of eight northern and four southern samples from 1945 material. The Duck, Black, Cam, Mersey, and Derwent Rivers are each represented by one sample, being the only available one containing at least 50 fish of each sex. The Leven and Forth are each represented by two samples, which were the first and last collected of the available samples containing at least 50 of each sex. The Huon was similarly represented by two samples obtained from the fishing area (Huonville), and a special non-commercial sample from downstream (Cradoc). The material of the first 11 samples was broadly representative of the catches at the localities from which they were drawn. Table 4 shows the occurrence of different maturity stages separately for the combined eight northern samples, the Derwent (New Norfolk) sample, the two Huonville samples and the Cradoc sample.

TABLE 4

NUMBERS AND PERCENTAGES OF FISH AT DIFFERENT MATURITY STAGES IN RANDOMLY SELECTED 1945 SAMPLES FROM THE STATED LOCALITIES

Locality	Sex	Filling		Full		Part-Spent		Spent		Total No.
		No.	%	No.	%	No.	%	No.	%	
Northern Tasmania	♀	43	10.8	340	85.0	17	4.2	—	—	400
	♂	5	1.2	271	67.8	124	31.0	—	—	400
Huon (Cradoc)	♀	—	—	50	100.0	—	—	—	—	50
	♂	3	6.0	47	94.0	—	—	—	—	50
Derwent	♀	—	—	48	96.0	2	4.0	—	—	50
	♂	—	—	34	68.0	16	32.0	—	—	50
Huon (Huonville)	♀	2	2.0	48	48.0	15	15.0	35	35.0	100
	♂	1	1.0	31	31.0	58	58.0	10	10.0	100

These results show that the females in the catch are less advanced in maturity than the males. They also show that the maturity-stage composition of the stock is much the same in the fishing areas of the northern streams, the Derwent, and the Cradoc sector of the Huon, which is not a fishing area. In all these places the fish are mainly full, and presumably ready to spawn, but the position is quite different at the Huon fishing area, where part-spent fish are relatively numerous and where spents also occur, although they are not taken elsewhere. It was mentioned in Section IV that the Huon fishery operates relatively far upstream, well above the estuarine delta, although in other streams where such a delta occurs the fishery is located in or very close to it. It is shown in Section VI that the larvae of *Lovettia* are most abundant in the deltaic section of the Huon, which includes Cradoc. In October 1945 the chlorinity of the water at Cradoc was only 0.08 parts per thousand, i.e. well within the range at which *Lovettia* are commonly found in other streams.

It is apparent that a large proportion of the fish which reach Huonville have already spawned downstream, whereas in other rivers the fishing and spawning areas are practically identical. Runs of fish similar in maturity-stage composition to the northern and Derwent *Lovettia* do occur downstream in the Huon, and runs similar to those at Huonville doubtless occur in the upper reaches of the other rivers.

This point is important because the Huonville whitebait are regarded as inferior to those of other areas for canning. It will readily be understood that the condition (fatness) of these fish is poorer because of the late stage of the reproductive cycle, and there are also differences in pigmentation which are discussed in Section IX. As far as maturity stages are concerned, however, the fish caught at Huonville obviously cannot be regarded as typical of those available in the Huon River.

In females classed as full, the number of large eggs is positively correlated with size of fish, as shown in Table 5. The increase in mean egg number is somewhat irregular for successive sizes of fish, but this could be due to the inclusion of specimens bordering upon the filling or part-spent maturity stages. The largest number of eggs found in a single female (54 mm.) was 310.

TABLE 5

MEAN NUMBERS OF LARGE EGGS IN SAMPLES OF FULL FEMALES OF THE STATED LENGTHS, FROM SAMPLES COLLECTED IN 1946

Length (mm.)	No. of Fish	Mean No. of Eggs	Locality
40	10	128.0	Huon
41	10	134.9	Huon
42	10	157.6	Huon
43	15	148.6	Huon
44	10	159.9	Huon
45	10	135.9	Huon
46	10	153.5	Mersey and Leven
47	16	181.9	Mersey and Leven
48	10	187.1	Mersey and Leven
49	17	187.8	Mersey and Leven
50	19	197.9	Mersey and Leven
51	10	205.9	Mersey and Leven

VI. EGGS AND LARVAE

It was shown in the previous section that the fishing areas in all the rivers except the Huon are broadly identical with the centres of spawning. The environmental features characteristic of these areas were mentioned in Section IV.

In the spawning areas, the extruded eggs may be found in great numbers adhering to logs, submerged branches, sticks, stones, and other vegetation-free surfaces below low water level. Plate 4, Figure 1, shows a typical cluster of eggs. The spawning act has not been seen, and it is not certain whether the eggs are fertilized before or after deposition. The eggs are sticky upon extrusion. The fertilized eggs are the same size as the ripe ovarian eggs (Section V). Professor Hickman and Mr. Paddon conducted independent experiments on artificial fertilization and rearing of whitebait eggs. The former found that the incubation period varied from 15 to 18 days at room temperature. The latter found it took 23 days. Figure 3 shows the developing egg.

Figure 3 shows one of the newly hatched larvae reared by Professor Hickman. It is 5.8 mm. in total length and most of the yolk has been absorbed. A mouth is present. The post-anal region is one-quarter of the total length, compared with two-fifths in the adult female (see Plate 1). The median fin fold is continuous and without signs of fin rays. The tail is diphycercal. Rudimentary pectoral fins are present. The eyes are pigmented and there is a narrow band of melanophores in the mid-ventral line between the head and anus, with a few melanophores elsewhere in the ventral region.

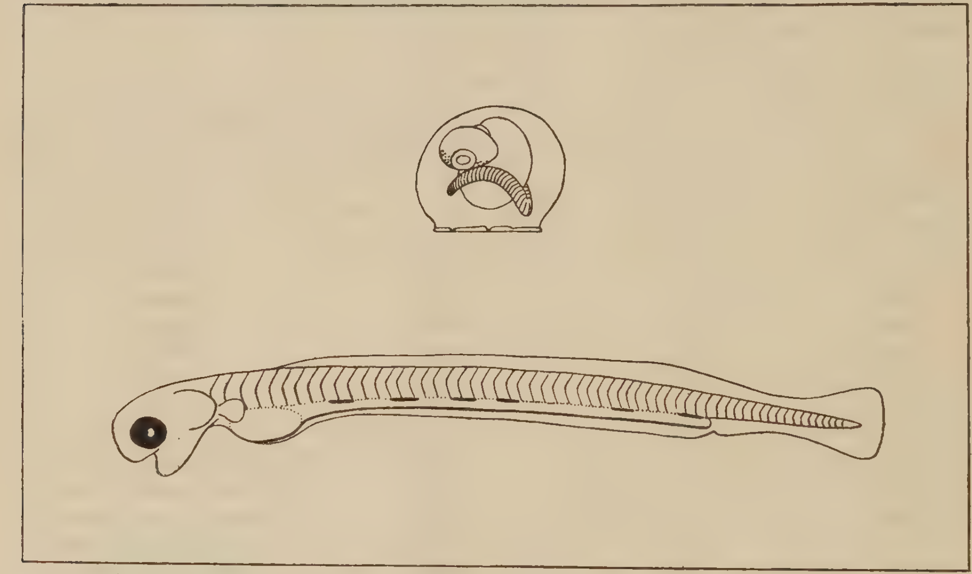


Fig. 3.—Developing egg, 1.1 mm. diameter, and newly hatched larva, 5.8 mm. total length, of *Lovettia seali* from Huon River. Egg has bark substrate, larva has yolk in late stage of absorption. The mid-ventral pigmentation of the larva is exaggerated. For further explanation see text.

On the Huon River in late October 1945, such larvae were taken in plankton nets. They ranged up to 7 mm. in total length and differed from the newly hatched stage merely in the complete absence of yolk, the appearance of caudal and pectoral fin rays, and the further development of ventral pigmentation. The line of melanophores along the mid-ventral line becomes continuous and very distinct anterior to the anus, and well developed although discontinuous posteriorly. Several hundred larvae were examined but the position of the anus showed no significant variation; as these must have included males, there must be a later metamorphosis in that sex to account for the situation described in Section III.

During the survey referred to, a "Discovery" N70 plankton net was towed at the surface for 15 minutes at each of 11 stations from Huonville to the mouth of the river. At Huonville itself, in the centre of the fishing area, only one larva was taken. At the station next downstream, but still within the fishing area, there were 38 developing eggs and no larvae. A few eggs, which were mostly mutually adherent and appeared to have become detached after deposition, were also found at other stations. The best catches of larvae were made further downstream still, in the deltaic islet area of the river (38 at Franklin, and many hundreds each at Cradoc and Jarvey's Bay). Further down, the numbers were smaller, but some larvae were found drifting out to sea at the entrance of the Huon. These results confirm those of the previous section as to the location of the main spawning area in the Huon: it is the unfished islet sector, and not the more upstream position where the fishing is done. They also show that *Lovettia* is a fully anadromous species with a marine phase, as foreshadowed in Section IV and further discussed in Section X.

VII. Length and Age

The 78,383 specimens of *Lovettia* of the samples listed in Tables 1 and 2, and 58 other specimens, were all measured in mm. of standard length, i.e. overall length excluding the caudal fin. The smallest fish were 33 mm., including some of both sexes, and these occurred only in the southern samples. The largest was 70 mm., a southern female. In the north the smallest measured 35 mm., including some of both sexes, and the largest was a 60 mm. female.

Tables 1 and 2 give for each sample the mean lengths of the male and female fish, wherever 100 or more of the same sex were available. The difference between each such pair of means (female length minus male length) is also stated.

Mean lengths of fish from unsorted commercial samples are usually of little value in biological studies. However, where a fishery operates for a short season on a single age-group the mean lengths of representative samples measure the growth rate, and may be used for growth rate comparisons. This is virtually the case with *Lovettia.*

Figure 4 shows four series of length frequency polygons, which have been smoothed by a moving average of 3. Each polygon shows the length composition of a single sample, separately for males and females where 100 or more of the same sex were available. Each series consists of several such polygons, representing samples taken in the same river at the same season. One southern and three northern rivers are represented. The Figure illustrates the following points:

(1) The sex ratio is highly variable, but males greatly predominate. This is further discussed in the next section.

(2) The length frequency distributions tend to be of the normal type, unimodal and often virtually symmetrical.

(3) Almost invariably the females of a sample tend to be larger than the males, but this difference is much more marked in the northern material.

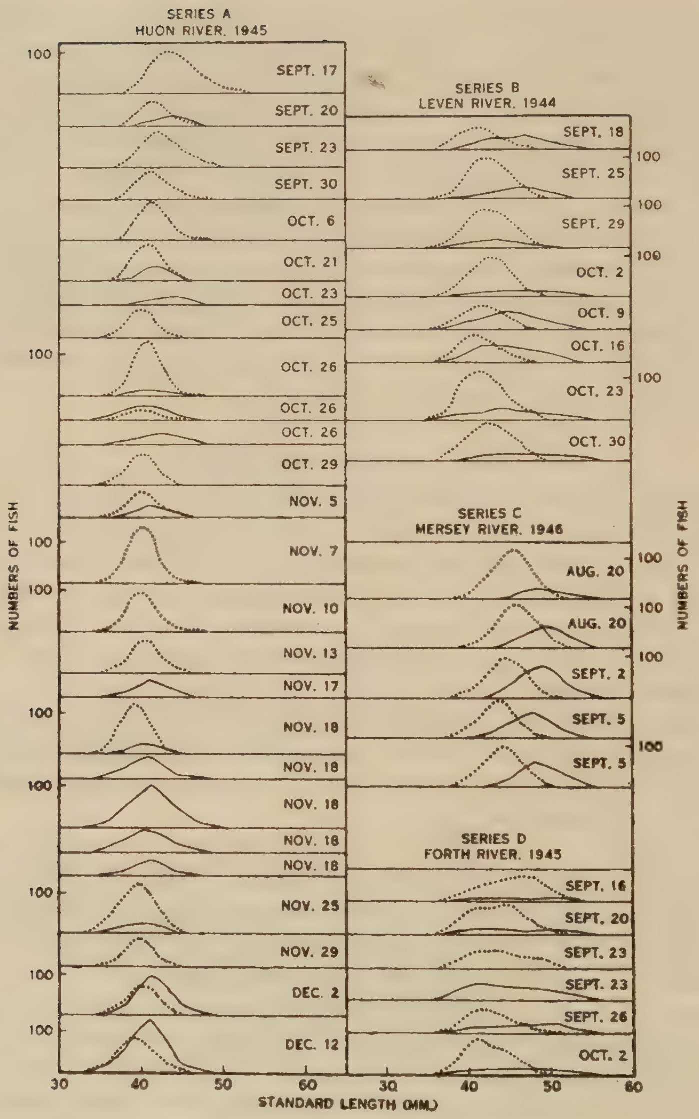


Fig. 4.—Length frequency polygons of four series of samples of *Lovettia seali*, smoothed by a moving average of three. Unbroken and broken lines are female and male polygons respectively. The series A polygons for October 26 and November 18 are in order of locality, the uppermost polygons representing the most upstream samples. The Series D polygons for September 23 are in order of time of day at the same locality, the upper polygon representing the first sample.

(4) Fish of both sexes tend to be larger in the north than in the south. This is discussed in Section XIV.

(5) There appears to be no significant variation in length with time in the same season at the same river.

Figure 4 shows beyond reasonable doubt that only one age-group is significantly represented in the stock fished in any river. The actual age must also be very nearly the same, twelve months or some constant multiple, in all the material, since the fishing season is always the spawning season. But because this season extends over about three months in both north and south (Section IV) and because the broods hatched in the different rivers do not maintain their separate identities up to the mature stage (Section X), the catch could include fish whose ages differed by weeks, or even months. This alone, apart from possible causes of real growth-rate variation, could account for the small differences in average length that are observable between samples of the same season at the same river, and for the slight tendency to bimodality in a few length frequency polygons. As regards the latter, it may be added that most of the samples were collected for the author by other people, and that some of them may have included fish caught at different times on the same day, i.e. from different shoals. This was not, however, the case at the Huon. Abnormal length frequency distributions are better represented in Figure 4 than they were in the whole material of Tables 1 and 2.

However, some of the southern samples contained a very few *Lovettia* which were so much larger than the others that it was impossible to regard them as of the same age. A study of length frequencies indicated that all those above 55 mm. were probably in this category. There were five such fish in the combined three samples from the Derwent River, and 25 in the 38 Huon samples. These, together with 28 others specially collected from the Huon, and not associated with the samples of Table 2, constitute the 58 fish mentioned above as not included in Tables 1 and 2. The largest of the 53 females was 70 mm., the largest of the five males 61 mm. The 30 large fish of the samples of Table 2 constitute 0.001 per cent. of the 30,293 other *Lovettia* in those samples. No trace of any such subsidiary age-group was found in the northern material, the largest individual of which measured only 60 mm.; this fish, a female, appeared merely to represent the extreme of a normal distribution of which the mean was 52.89 mm. and the smallest member 47 mm. As northern whitebait tend to be larger than southern, the maximum size in any group corresponding to the large southern fish would probably measure over 70 mm.; such fish should certainly have been found if they were represented in the northern commercial catch.

These observations on age composition can be understood by reference to investigations on the life histories of other anadromous salmonoids. It is well known that Pacific salmons (*Oncorhynchus* spp.) ascend rivers and spawn once, and then all die. In one species, the pink salmon (*O. gorbuscha*), all the spawning fish are the same age, namely two years (Davidson 1934). In the Japanese ayu (*Plecoglossus altivelis*) the ascending runs consist of one-year fish which nearly all die after spawning, but a very few, all females, survive for another year without returning to the sea (Nomura 1922). In the Atlantic salmon (*Salmo salar*) there is a high mortality after spawning, which especially affects males (Norman 1931, p. 285). In the European smelt (*Osmerus eperlanus*) there are four age-groups, but the oldest is poorly represented and contains females only (Masterman 1913).

Anticipating the subsequent identification of the groups by age, it may be concluded that the life cycle of *Lovettia* is very like that of the ayu, and has also some resemblance to that of pink salmon. Nearly all the fish in the spawning runs of *Lovettia* are one year old, and die at the end of the season; but a minute proportion, in which females greatly predominate, survive to become two years old, probably without descending the stream. There is no direct evidence that the fish die, but such evidence is notoriously hard to procure and some authors (e.g. Ricker 1945, pp. 120-1) attach little importance to the lack of it. Mass mortality is deduced, firstly, from the insignificant representation of older age-groups, secondly, from the extremely poor condition of the spent fish (Sections V and IX), and thirdly, from consideration of life histories of related forms. With regard to the first point, the presence of a few older fish is actually better evidence than their complete absence would be, because in the latter case it might be argued that the stock had merely changed its habits. In any event the fish are lost to the whitebait fishery even if they do not die. The suggestion that the survivors remain in the rivers follows from the fact that they have been found in the southern but not in the northern streams. It was shown previously that the Huon and Derwent fisheries operate relatively far upstream, and the former upon shoals which have largely finished spawning, whereas the northern fisheries catch the fish nearer the sea at an earlier stage of reproduction. If the survivors of the principal age-group remained in the upstream waters, it would explain their presence in the southern samples and their absence in those of the north. That is to say, there are probably similar survivors in the north, but they do not return even as far downstream as the fishing areas, and so are not caught.

The average male size was greater for only two of the 68 samples for which there were 100 or more fish of each sex, and these were both southern material. There were 24 such samples of southern fish, and the difference (female minus male length) ranged from —1.04 to 2.49, mean 1.02 mm. Similar differences for the 44 northern samples ranged from 0.83 to 4.74, mean 3.27 mm.

The fish in the principal age-group are considered to be one year old. As nothing is known of the life history between the young larval and sexually mature stages, and as *Lovettia* has no scales, the evidence is based entirely on otolith studies. About 70 otoliths were examined from three samples specially preserved in alcohol: these were taken at the Huon in late October 1945, the Leven in early September 1946, and the Huon (large fish of the subsidiary age-group) in 1946. The otoliths of the first two samples were about 0.7 to 0.9 mm. long. Plate 3, Figures 1 and 2, shows otoliths from a Leven female of 49 mm. and a Huon male of 45 mm. respectively, seen by reflected light. These were typical of the respective groups, and the otolith examinations left no doubt that, whatever the age, it was the same for all sizes of fish in the sample.

The Leven otoliths were peculiar. As Plate 3, Figure 1, shows, there is a narrow opaque (white) zone at the edge followed by a well-defined translucent (dark) ring, with another opaque zone inside that. But the inner margin of the last-mentioned zone is ill-defined, and there is some grading into the next zone, which makes up the bulk of the otolith, and is translucent. Finally, there is an irregularly shaped opaque mass at the centre of the structure. In the Huon otoliths there is again an opaque zone at the edge, followed by a translucent ring, but beyond that the object is opaque to the centre.

It appears that the Leven material represents a slightly earlier stage in the development of the whitebait otolith than does that of the Huon. The intermediate opaque zone varies considerably in breadth in different specimens, and occasionally extends almost to the centre. The innermost opaque zone also varies in size and always appears very distinct from the rest of the otolith substance, especially in transmitted light: it is relatively very opaque and irregular in outline, and appears to be of organic character. Hickling (1931) has shown that the fish otolith consists primarily of a fibrous basketwork within which the supporting crystalline constituent is secreted. A Leven whitebait otolith was decalcified, but the material of the innermost opaque zone was unchanged in appearance. It was also observed that the Leven otoliths became covered with large fissures on the surface when transferred from alcohol to xylol, or when allowed to dry, although this was not the case with the Huon material. It can only be concluded that the calcification of the Leven otoliths was incomplete, especially at the centre, whereas the process was more advanced in the Huon otoliths.

It has generally been held that an opaque and a translucent zone together represent a year's growth, though there is no unanimity about the seasons of the year that the respective zones represent (e.g. Dannevig 1933, esp. p. 82; Hickling 1933). On this basis the *Lovettia* otoliths must be one year old, and certainly cannot be two years, since there is only one translucent zone even though two opaque zones are present. The outer opaque zone is very narrow in the Leven specimens, and the appearance of the material from both rivers merely suggests the commencement of a second year's growth. Even this is illusory in view of the fact that the average age must be exactly twelve months. A reasonable hypothesis is that the translucent zone is formed in winter and the opaque zone during the rest of the year. Thus the large inner opaque zone would represent the growth of the warmer months immediately following hatching, and the marginal opaque ring the commencement of another such period, normally cut short by death. This could explain the relatively wider marginal ring in the Huon material, since this was obtained later in the spring than the Leven material. This would also appear to be the period at which calcification of the otolith is completed.

The otoliths of the large fish which survive the first year generally showed an additional translucent ring and narrow marginal opaque ring, indicating that they were actually two years old. They ranged up to 1.1 mm. long. One or two of the largest specimens were doubtful and could have been reckoned as three years old. This may, however, have been due to the presence of a secondary ring. Secondary rings were occasionally encountered in the younger Huon River otoliths, but were recognizable as such by their infrequency and their spacing. At least most of the survivors of the one-year fish do not live beyond two years, and the three-year-olds, if any, form a very minute proportion indeed of the total stock. In subsequent references, these larger whitebait are referred to as being all two years old.

VIII. SEX RATIO

The data of Tables 1 and 2 show that the sex ratio is highly variable in samples of *Lovettia,* although only one sample consisted wholly of fish of the same sex. This was the single sample procured at night, when all were males (Huon, October 25, 1945). Sometimes there is a high preponderance of females, sometimes of males, but the latter is more usual. The lowest and highest numbers of males per 100 females were respectively 4 and 6893, both in northern samples (Duck, September 12, 1946; Forth, September 23, 1945). However, a range of a similar order, from 5 to 5343, is found in southern samples (Huon, November 18 and 13, 1945). The numbers of males per 100 females are 223 and 230 for the grand totals of northern and southern fish respectively, and 225 (54,288 males and 24,095 females) for the combined material. If the 325 males of the night sample are omitted the figure becomes 226 males for the south and 224 for the whole State. The few two-year southern fish have been ignored in these compilations.

On two occasions at the Huon (October 26 and November 18, 1945) and once at the Leven (September 21, 1945) samples were taken from separate shoals at different parts of the stream on the same day. In each instance the number of males per 100 females was consistently less at successive downstream positions.

Similar fluctuations in sex ratio, with an overall predominance of males, have been recorded in several species of Osmeridae, the true smelts (Masterman 1913; Hoover 1936; Hart and McHugh 1944; Templeman 1948).

IX. PIGMENTATION

Although the Huon was the first river in which whitebait were taken for canning, the demand for the fish of this area declined when it was found that whitebait of a lighter colour could be taken abundantly in the northern streams. *Lovettia* is translucent when alive, but the dead fish is usually opaque white, with or without some development of black spots on the skin, and sometimes almost wholly black.

The 1200 fish examined for maturity stages (see Section V) were also classified as to colour stages. Five stages of successively increasing pigmentation were recognized, as follows:

(1) No spots on the body, or less than 10 on the posterior part of the back.
(2) Spots numerous on the back, but not extending right to the head.
(3) Spots on the back extending to the head, but less than five on the posterior end of each lateral line.
(4) Spots more numerous on the lateral line, but not continuous over more than six to eight segments.
(5) Lateral line pigmentation further developed.

TABLE 6

NUMBERS OF FISH AT DIFFERENT MATURITY AND COLOUR STAGES IN RANDOMLY SELECTED 1945 SAMPLES FROM THE STATED LOCALITIES

Locality	Colour	Filling		Full		Part-Spent		Spent	
		♀	♂	♀	♂	♀	♂	♀	♂
Northern Tasmania	1	18	4	125	44	—	2	—	—
	2	23	1	195	171	9	20	—	—
	3	2	—	20	45	8	71	—	—
	4	—	—	—	11	—	29	—	—
	5	—	—	—	—	—	2	—	—
Huon (Cradoc)	1	—	1	1	3	—	—	—	—
	2	—	2	25	26	—	—	—	—
	3	—	—	21	15	—	—	—	—
	4	—	—	3	3	—	—	—	—
Derwent	1	—	—	2	1	—	—	—	—
	2	—	—	22	7	—	—	—	—
	3	—	—	23	21	1	10	—	—
	4	—	—	1	5	1	6	—	—
Huon (Huonville)	1	—	—	—	—	—	—	—	—
	2	—	1	9	2	—	2	—	—
	3	2	—	27	14	1	17	5	—
	4	—	—	12	4	8	13	20	1
	5	—	—	—	11	6	26	10	9
Southern Tasmania (Huon and Derwent)	1	—	1	3	4	—	—	—	—
	2	—	3	56	35	—	2	—	—
	3	2	—	71	50	2	27	5	—
	4	—	—	16	12	9	19	20	1
	5	—	—	—	11	6	26	10	9

Samples of whitebait which are predominantly of stages 1-2, 3, and 4-5 are respectively regarded as good, fair, and unacceptable for canning purposes. Table 6 shows the information of Table 4 (Section V) further analysed as to colour stages.

The data for the different localities show that the successive gonad-maturity stages are generally characterized by increased pigmentation of the fish. This is especially evident if the figures are compared separately for the sexes, because males tend to be darker than females at the same maturity stage. It is also evident that southern whitebait are slightly more pigmented than northern fish of the same sex, at comparable maturity stages: in the south colour stage 1 is relatively uncommon and stage 3 is strongly represented, even among filling and full fish.

Irrespective of maturity stage, the peritoneum of the male *Lovettia* tends to be much darker than that of the female. In filling and full fish, which are usually fat and well-conditioned, this difference is not often apparent externally; but in the part-spent and spent stages, at which the fish become gradually leaner, this internal pigmentation of males is generally perceptible, and contributes to the dark appearance. Plate 1, Figures 1-3, shows typical female *Lovettia* which are respectively full, part-spent, and spent, and Plate 2 shows a similar series for males, all specimens being from the Huon. The increasing leanness and pigmentation of the fish at the later maturity stages are well demonstrated.

This increase in pigmentation is comparable to that of the Atlantic salmon (*Salmo salar*) and other species at the spawning season. It is thought that the transference of somatic material to the gonads leads, in the salmon, to the rapid formation of an excess of by-products, which the fish is unable to excrete, and which thus appear as skin pigment (Norman 1931, p. 284). This hypothesis would explain the situation in *Lovettia* very well.

The darker colour of the southern fish, stage for stage in fish of the same sex, appears to be an inherent character by which large samples may be identified as being of northern or southern origin. However, it is clear that whitebait comparable in pigmentation to much of that utilized commercially in the north are available in the southern waters also, although not as a rule at Huonville. The Derwent (New Norfolk) whitebait are superior to those taken at Huonville, and the single sample from Cradoc is better than either. The latter was collected in the course of a special survey of the Huon in October 1945, which was undertaken in the belief that *Lovettia* of a better colour would be found in abundance in the deltaic area. The fish were found plentifully at Cradoc and doubtless could have been located at other places. The single sample taken may not be quite typical of the fish available in this part of the river, but it seems certain, from the argument of Section V and the observations here, that the Huonville whitebait are not typical of those in the Huon River; and further, that in any river where the colour of the fish is objectionable better results can be expected from fishing further downstream.

There is therefore probably no good reason why the Derwent, Huon, and other southern streams should not prove to be a good source of fair though not best quality whitebait. The 200 fish of the combined New

Norfolk and Cradoc samples in Table 6 were 4, 41, 45.5, and 9.5 per cent. respectively of fish of colour stages 1, 2, 3, and 4. The 800 northern fish were 24.1, 52.4, 18.2, 5.0, and 0.2 per cent. stages 1, 2, 3, 4, and 5 respectively. The difference is still in favour of the northern material, but not greatly so, and the southern fish would be of acceptable standard for canning.

TABLE 7

SUMMARY OF VERTEBRA COUNTS AND MEANS FOR SAMPLES OF 12 RIVERS, NEGLECTING SKELETONS WITH ABNORMAL VERTEBRAE

River	Vertebrae										No.	Mean
	52	53	54	55	56	57	58	59	60	61		
Male:												
Derwent	1	2	7	21	8	1					40	54.90
Huon		1	7	26	7						41	54.95
Esperance		1	6	18	13	2					40	55.23
Duck			12	17	10	1	1				41	55.07
Black		1	14	15	10	1					41	54.90
Inglis		1	7	13	13	4					38	55.32
Cam		3	8	17	10						38	54.89
Leven		3	7	21	10	3					44	55.07
Don		2	8	18	9						37	54.92
Mersey			10	22	10						42	55.00
Rubicon		1	13	24	3	2					43	54.81
Franklin		2	9	18	10	1					40	54.98
Total Male	1	17	108	230	113	15	1				485	55.00
Female:												
Derwent		4	12	16	2	1					35	54.54
Huon		5	12	15	3	1					36	54.53
Esperance		1	15	18	7	1					42	54.81
Duck		2	11	19	6	1					39	54.82
Black		4	12	21	4	1					42	54.67
Inglis		1	17	16	5	1					40	54.70
Cam		1	10	21	7	1					40	54.93
Leven	2	1	18	13	8						42	54.57
Don		7	8	21	5	1					42	54.64
Mersey		2	12	19	7						40	54.78
Rubicon		1	8	15	10						34	55.00
Franklin		1	11	16	9						37	54.89
Total Female	2	30	146	210	73	8					469	54.74

X. ANALYSIS OF POPULATIONS

It was felt that there was more than one population of *Lovettia*, and that the populations would require different management treatment because of unequal alteration by the fishery. Since tagging was out of the question, the most promising line of enquiry appeared to be variation in mean vertebra number. The vertebrae were counted in 50 fish of each sex for each of 12 rivers, 9 northern and 3 southern. The material was all collected in 1946 and contained no fish which could be regarded as two years old. It was therefore homogeneous as to year-class and age-group. The fish were stained in alizarin according to the method of Raitt (1935) and all counts were made by the author.

TABLE 8

SUMMARY OF VERTEBRA COUNTS AND MEANS FOR SAMPLES OF 12 RIVERS, EACH ABNORMAL VERTEBRA COUNTED AS 1

River	Vertebrae										No.	Mean
	52	53	54	55	56	57	58	59	60	61		
Male:												
Derwent	1	3	12	24	9	1					50	54.80
Huon		1	15	26	8						50	54.82
Esperance		2	7	23	16	2					50	55.18
Duck		1	18	18	11	1	1				50	54.92
Black		2	15	20	12	1					50	54.90
Inglis		3	11	18	14	4					50	55.10
Cam		3	14	20	13						50	54.86
Leven		4	10	22	11	3					50	54.98
Don		4	13	24	9						50	54.76
Mersey			14	25	11						50	54.94
Rubicon		2	15	26	4	2			1		50	54.88
Franklin		2	10	24	13	1					50	55.02
Total Male	1	27	154	270	131	15	1		1		600	54.93
Female:												
Derwent	1	6	18	19	3	3					50	54.52
Huon		8	16	20	5	1					50	54.50
Esperance		1	20	20	8	1					50	54.76
Duck		4	15	24	6	1					50	54.70
Black		5	16	23	5	1					50	54.62
Inglis		2	25	17	5	1					50	54.56
Cam		1	18	23	7	1					50	54.78
Leven	2	4	21	14	9						50	54.48
Don		7	12	25	5	1					50	54.62
Mersey		3	17	22	7	1					50	54.72
Rubicon		5	16	18	11						50	54.70
Franklin		3	16	22	9						50	54.74
Total Female	3	49	210	247	80	11					600	54.64

The urostyle, which generally bore 1 or 2 spines (occasionally none or 3) was not counted. Vertebrae with 2 neural spines occurred in 246 of the 1200 skeletons. In 242 of these only the last vertebra was abnormal; in 1 case only the second last; in 1 case the last two; in 1 case the last and fifth last (50th); and in 1 case the 45th and 46th. Such backbones may be dealt with by: (*a*) neglecting them altogether, i.e. basing the sample means only on counts from normal skeletons; (*b*) counting each abnormal vertebra as 1; (*c*) counting each as 2; or (*d*) counting each as 1½. Method (*d*) has sometimes been used because mean vertebra numbers so determined generally correspond best with those obtained in the same samples by method (*a*). This applies in *Lovettia* also but does not in itself justify the method. Actually none of these methods is indisputably

TABLE 9

SUMMARY OF VERTEBRA COUNTS AND MEANS FOR SAMPLES OF 12 RIVERS, EACH ABNORMAL VERTEBRA COUNTED AS 2

River	Vertebrae										No.	Mean
	52	53	54	55	56	57	58	59	60	61		
Male:												
Derwent	1	2	8	26	11	2					50	55.00
Huon		1	7	34	7	1					50	55.00
Esperance		1	7	19	18	5					50	55.38
Duck			13	23	11	2	1				50	55.10
Black		1	15	16	15	3					50	55.08
Inglis		1	9	17	18	5					50	55.34
Cam		3	8	23	13	3					50	55.10
Leven		3	8	24	11	4					50	55.10
Don		2	10	23	15						50	55.02
Mersey			10	26	13	1					50	55.10
Rubicon		1	14	26	5	3				1	50	55.02
Franklin		2	9	19	16	4					50	55.22
Total Male	1	17	118	276	153	33	1			1	600	55.12
Female:												
Derwent		5	14	22	5	2	2				50	54.82
Huon		5	15	19	8	3					50	54.78
Esperance		1	15	23	9	2					50	54.92
Duck		2	13	22	12	1					50	54.94
Black		4	13	25	6	2					50	54.78
Inglis		1	18	24	6	1					50	54.76
Cam		1	10	29	9	1					50	54.98
Leven	2	1	21	14	11	1					50	54.68
Don		7	8	25	9	1					50	54.78
Mersey		2	13	24	10		1				50	54.92
Rubicon		1	12	23	13	1					50	55.02
Franklin		1	13	21	15						50	55.00
Total Female	2	31	165	271	113	15	3				600	54.86

the ideal, although (*c*) is probably the most reliable (Gabriel 1944, pp. 128-32 and references).

It was decided to analyse the data as compiled by procedures (*a*), (*b*), and (*c*). The raw data and means are given in Tables 7-9, in which the rivers are listed in their clockwise geographical order around Tasmania. The only striking feature is the tendency towards higher means in males; of the 36 comparisons, 33 favour the males, 2 favour the females (Cam and Rubicon in Table 7), and 1 shows parity (Rubicon in Table 9).

A statistical analysis of all the data, which was made by staff of the Section of Mathematical Statistics, C.S.I.R.O., showed that the means for different rivers or for the northern and southern groups of rivers do not differ significantly by any of the counting procedures. There is therefore no evidence of the existence of more than one population of fish as far as this character is concerned. The counts for each sex by each method may therefore all be combined, and the final three pairs of means tested for significance of difference. This information is summarized in Table 10, which shows that the mean for males is in each case higher than that for females by more than four times the standard error of the difference. The differences are therefore significant at the 1 per cent. level of probability.

TABLE 10

MEAN VERTEBRA NUMBERS FOR SEXES, MATERIAL OF ALL LOCALITIES COMBINED, WITH DIFFERENCE AND STANDARD ERROR OF DIFFERENCE, BY THREE METHODS OF COUNTING

Counting Method	♂		♀		Difference	Standard Error of Difference
	No.	Mean	No.	Mean		
Skeletons with abnormal vertebrae omitted	485	55.00	469	54.74	0.26	0.06
Abnormal vertebrae counted as 1 each	600	54.93	600	54.64	0.29	0.05
Abnormal vertebrae counted as 2 each	600	55.12	600	54.86	0.26	0.05

Sexual dimorphism in vertebra number is very rare in fishes. Hart (1937), Hart and McHugh (1944, pp. 4, 21-2), and Templeman (1948) have found well-marked differences in three osmerids.

Counts of fin rays were attempted, but abandoned because of the difficulty of adhering to a consistent counting system. In the end, it was found impossible to distinguish populations by measurable morphological characters. However, the whitebait of the northern and southern fisheries can be distinguished by the study of numerous samples, and certainly represent independent populations. One distinguishing character is the growth rate, i.e. average size at the same age, which is usually (but variably) greater in the northern material (Section VII, see also

Section XIV). Another is the difference between the average size of females and males at the same age, which averages some 2 mm. more in northern material (Section VII). A third difference is that of pigmentation, which is slightly more extensive in southern than in northern fish of the same sex and maturity stage (Section IX). It might sometimes be difficult to decide whether a given sample belonged to the northern or southern population, but a decision could probably be given on two or three samples.

TABLE 11

TASMANIAN WHITEBAIT CATCH (LB.) FOR EACH OF THE YEARS 1941-1948 DISSECTED BY RIVERS OF ORIGIN

	1941	1942	1943	1944	1945	1946	1947	1948
North Coast								
Forester*					1,000	99,000	2,000	16,000
Rubicon			58,000	10,000	10,000	23,000	15,000	4,000
Mersey	1,000		123,000	88,000	135,000	337,000	300,000	104,000
Don						5,000	5,000	3,000
Forth				18,000	19,000	41,000	36,000	6,000
Leven			17,000	71,000	125,000	58,000	353,000	116,000
Blyth							48,000	1,000
Cam					8,000	14,000	26,000	2,000
Inglis						76,000	101,000	22,000
Black					23,000	76,000	91,000	19,000
Duck						21,000	62,000	32,000
Total	1,000		198,000	187,000	321,000	750,000	1,039,000	325,000
South Coast								
Huon	44,000	42,000	4,000	16,000	35,000	22,000	24,000	16,000
Derwent	8,000	4,000	4,000	3,000	1,000	2,000	2,000	1,000
Norfolk Bay								6,000
Total	52,000	46,000	8,000	19,000	36,000	24,000	26,000	23,000
Total Tasmania	53,000	46,000	206,000	206,000	357,000	774,000	1,065,000	348,000

* Including the Old and New Great Forester and Little Forester Rivers and other streams in the Bridport area.

Neither of these populations is divisible into further components on the basis of any character so far studied, and it seems certain that at least the northern one is homogeneous. This could easily be so because the *Lovettia* fry are carried down to sea (Section VI), and the distribution evidence strongly suggests that the marine phase covers most of the life of the fish (Section IV): this would provide opportunity for the intermingling of the broods hatched in different rivers. Table 11 shows the dissection of the State catch in each of the years 1941-1948, according to the rivers in which the fish were taken. The 1948 northern catch is much lower than that of 1946 or 1947, and it is shown in Section XIV that this represents a real decline in the abundance of fish in every part of that area. This affected every north coast stream, as the river catches show: only in the Forester River area was the 1948 catch not lower than that of 1947, and there both the 1948 and 1947 catches were much less than that of 1946. This uniformity is understandable on the basis of a homogeneous northern stock, but not otherwise.

Although only one sample from the Forester River was examined, and it contained less than 100 females, it was clearly referable to the northern population: the mean size of the males was higher than that recorded for any southern sample (Tables 1 and 2) and the distribution of pigmentation stages was typical of northern fish.

XI. FOOD, PREDATORS, AND PARASITES

The 1200 *Lovettia* classified by maturity and colour stages (Sections V and IX) were also examined for signs of food in the stomachs. Of these, 101 (8.4 per cent.) had food in the stomachs, and 63 were males and 38 females, although the sexes were equally represented in the total material. One sample of 50 males included 23 that contained food.

The 101 fish in question comprised 5, 65, 29, and 2 at the filling, full, part-spent, and spent maturity stages respectively, the percentages being 4.9, 64.4, 28.7, and 2.0. In the total 1200 the proportions were rather similar, the numbers at the respective stages being 54, 869, 232, and 45 (see Table 4) and the percentages 4.5, 72.4, 19.3, and 3.8.

The stomach contents were not identified in detail, but they comprised the eggs and fry of *Lovettia* itself, small purplish amphipods, and various insects, including mayfly and stonefly nymphs, caddis-fly larvae, free-living dipterous pupae, and (in one instance) a juvenile cockroach. Mr. A. D. Butcher assisted in identifying the insects.

No special study of the predators of *Lovettia* was made. As noted in Section IV, barracouta and rock cod eat the species. Other predators include Australian salmon (*Arripis trutta*), school shark (*Notogaleus rhinophanes*), and, according to Paddon (personal communication), mullet (*Agonostomus forsteri*), eels, and terns and other aquatic birds. Many fishermen and most amateur anglers also affirm that the introduced brown trout (*Salmo trutta*) eats *Lovettia* freely, but Paddon (1947) has stated that it does not do so as a rule, and that it prefers *Galaxias*. Most trout anglers in northern Tasmania have opposed the whitebait fishery, in the belief that a valuable trout food would be lost through depletion. However, the foregoing observations on the feeding of *Lovettia* suggest that this species itself competes for food with the brown trout, and even if the trout do eat many *Lovettia* it is rather an open question whether the presence of a large stock of *Lovettia* in a river makes more or less food available for trout.

Crowcroft (1947, pp. 13-16) described the trematode *Parahemiurus lovettiae* from the intestine of *Lovettia*. Other parasites include metacercariae of the trematode *Acanthostomum,* represented by subdermal cysts with local melanosis; the larval nematode *Capsularia marina* (L.), in the oesophagus and coelome; and the immature stage of a caligoid copepod, on the pelvic and anal fins. Professor T. H. Johnston and Dr. A. G. Nicholls gave assistance with the identifications.

XII. Associated Species

Tables 1 and 2 show the numbers of fish of species other than *Lovettia* in the 95 whitebait samples received. These species were the salmonoids *Galaxias truttaceus* (Cuvier), *G. attenuatus* (Jenyns), and *Retropinna tasmanica* McCulloch; the gobies *Tasmanogobius lordi* (Scott) and *Ctenogobius tamarensis* (Johnston); and the atherine *Atherinosoma tamarensis* (Johnston). The writer is obliged to Mr. I. S. R. Munro for the identifications of the last three species. The total numbers of these species were respectively 1311, 204, 25, 30, 4, and 1, 1575 variants in all. Scott (1936*b*, p. 133) had previously noted the occurrence of both species of *Galaxias* with the runs of *Lovettia.*

These variants predominated over *Lovettia* in only two of the 95 samples, and were altogether absent in 57 samples. The total of 1575 variants is 2 per cent. of the total of 79,958 fish listed in Tables 1 and 2. Apart from the two mentioned above, the best samples for representation of whitebait variants are two from the Huon (October 25 and November 7, 1946) in each of which these species account for only 9 per cent. Statements by north coast buyers indicate that *Galaxias truttaceus,* the principal variant, does not run until late in the whitebait season and is little esteemed because of its pigmentation (Section IV), so that even in the Forth, a "late" river, it comprises only about 5 per cent. of the season's catch. It can safely be said that over 95 per cent. of the Tasmanian fish marketed as whitebait are *Lovettia.*

Galaxias truttaceus occurs in Tasmania, Victoria, and Western Australia (Scott 1941, p. 56; Whitley 1944, p. 264). The specimens in the author's samples ranged from 32 to 60 mm. in standard length. Scott found that fish of comparable size entered a north Tasmanian stream mainly in late September and early October (pp. 60-2). They represent the upstream migration of fry hatched at or near the sea, probably in the preceding autumn (p. 68). Scott was almost certain that *G. truttaceus* was catadromous, although he had no specimens actually collected from the sea (pp. 58-9). The matter is now beyond doubt, as juveniles (32 to 49 mm. standard length) were collected in November 1948 at vessel anchorages in Great Taylor Bay, Pirates Bay, Wineglass Bay, Bay of Fires (all Tasmania), and Refuge Cove (Victoria).

Galaxias attenuatus occurs in all Australian states except Western Australia, as far north as Brisbane (Marshall 1928), and in New Zealand and southern South America, including the Falklands (Scott 1936*a*, p. 90). The specimens in the whitebait samples ranged from 36 to 52 mm.

in standard length. Scott (1938, pp. 120-9) and others have shown that such fish represent a spring upstream migration of fry, similar to that of *G. truttaceus*. Scott found them most commonly in October in a north Tasmanian stream, and thought they were hatched about the preceding autumn. New Zealand investigators (Phillipps 1940, pp. 25-34; and references there and in Scott 1938) have drawn similar conclusions. The catadromous habit of this species has long been known. The adults return upstream before the fry ascend.

The specimens of *Retropinna tasmanica* ranged from 24 to 59 mm. standard length. This species, which can be distinguished from all others by the number of transverse scale rows, occurs only in Tasmania and is the only member of the genus there (McCulloch 1920, p. 54; Stokell 1941). It is probably catadromous as is *R. retropinna* in New Zealand (Phillipps 1940, pp. 53-7).

In the whitebait runs *Galaxias* and *Retropinna* usually occur in small groups, which may move about irregularly for some time at the same place, by contrast with the purposeful, continuous, upstream movement of the much larger shoals of *Lovettia*.

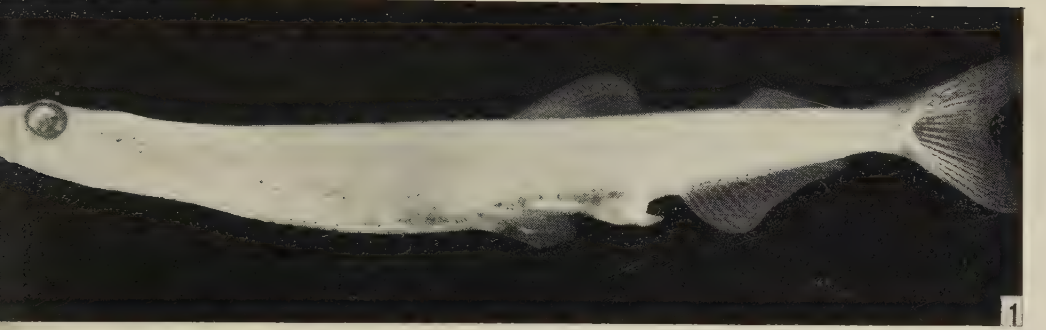
The commercial whitebait of New Zealand are the ascending spring fry of *Galaxias attenuatus* and *Retropinna retropinna*, the former species being preferred by buyers (Phillipps 1940). According to the author's colleague, Mr. A. M. Rapson, the whitebait canned in New Zealand is entirely *Galaxias*.

XIII. History of the Fishery

The history of the whitebait fishery is epitomized in Table 11, which shows the approximate catch of each season dissected by rivers of origin. This information was compiled mainly from confidential returns made to the author by whitebait buyers. The seasonal catch totals as shown by fishermen's returns were always much lower, although these returns gave higher totals for a few minor rivers which the buyers probably regarded as unimportant. Thus in Table 11 the figure for any stream in any year is the total as revealed by the buyers' or fishermen's returns, whichever was the greater.

Actually there are separate northern and southern fisheries, corresponding to the two populations recognized in Section X. The southern fishery began first, in 1941, but has not developed. The reasons for this were given in Section IX. Only a few fishermen (all part-time) operate in the south, and most of the catch of recent years has been sold fresh.

The northern fishery began in 1943 and was an immediate success. At first the whitebait were all sent to be canned in the south, but later there were canneries in the north and most of the catch was packed there. The 1943 and 1944 seasons represent the experimental phase of the fishery, when a small number of men fished only a few adjacent streams, being rather uncertain about the continuance of the demand. By 1945 it



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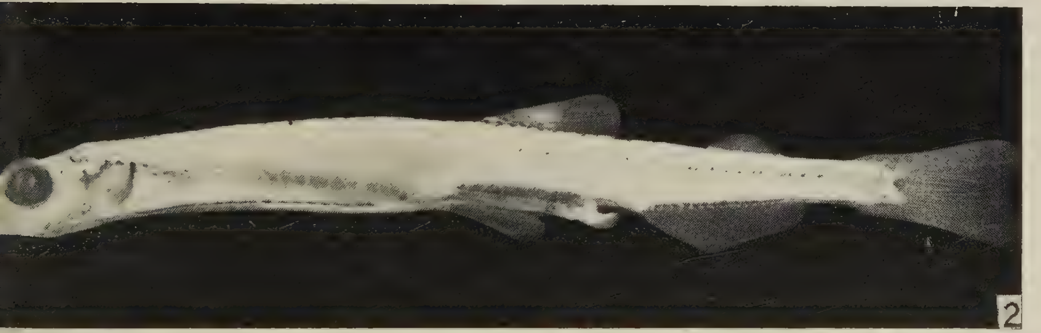

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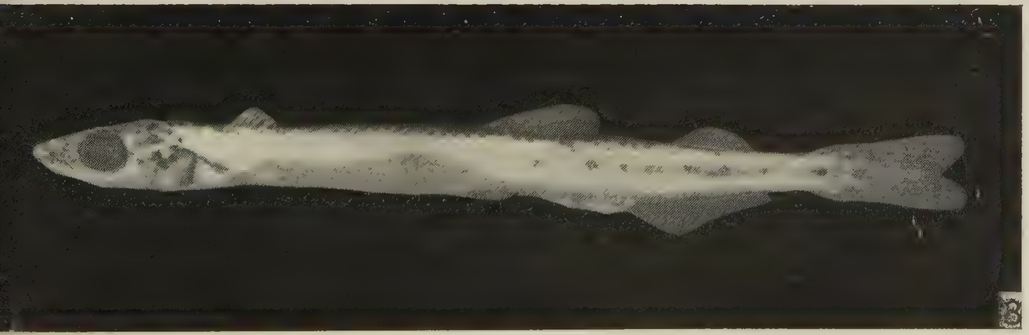
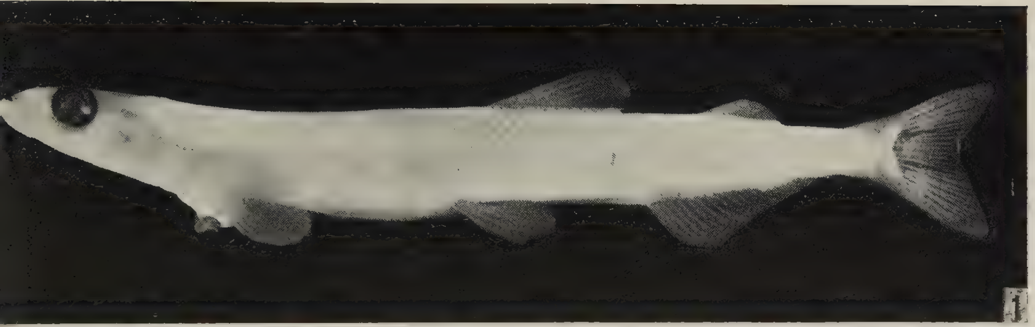


3

BLACKBURN.—THE TASMANIAN WHITEBAIT, LOVETTIA SEALI (JOHNSTON), AND THE WHITEBAIT FISHERY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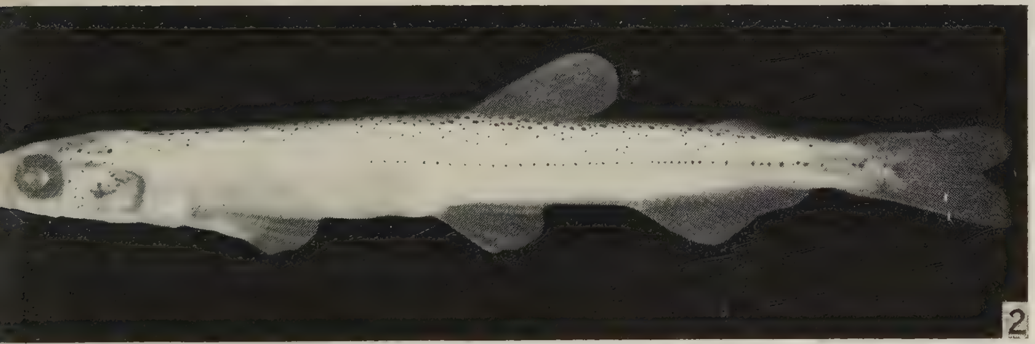
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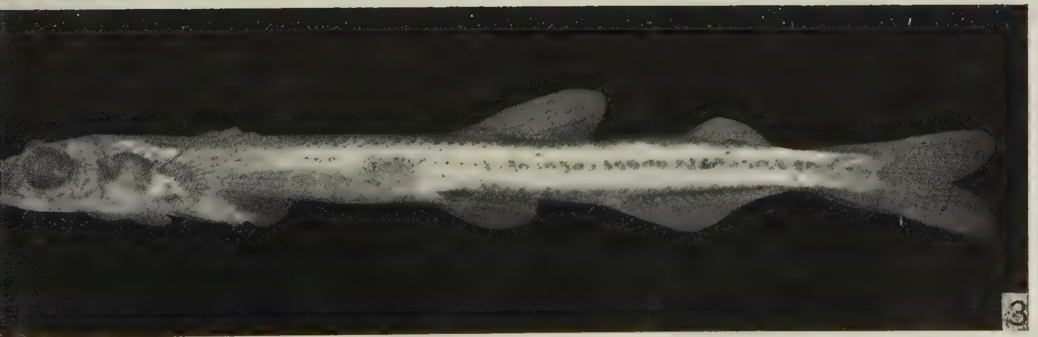
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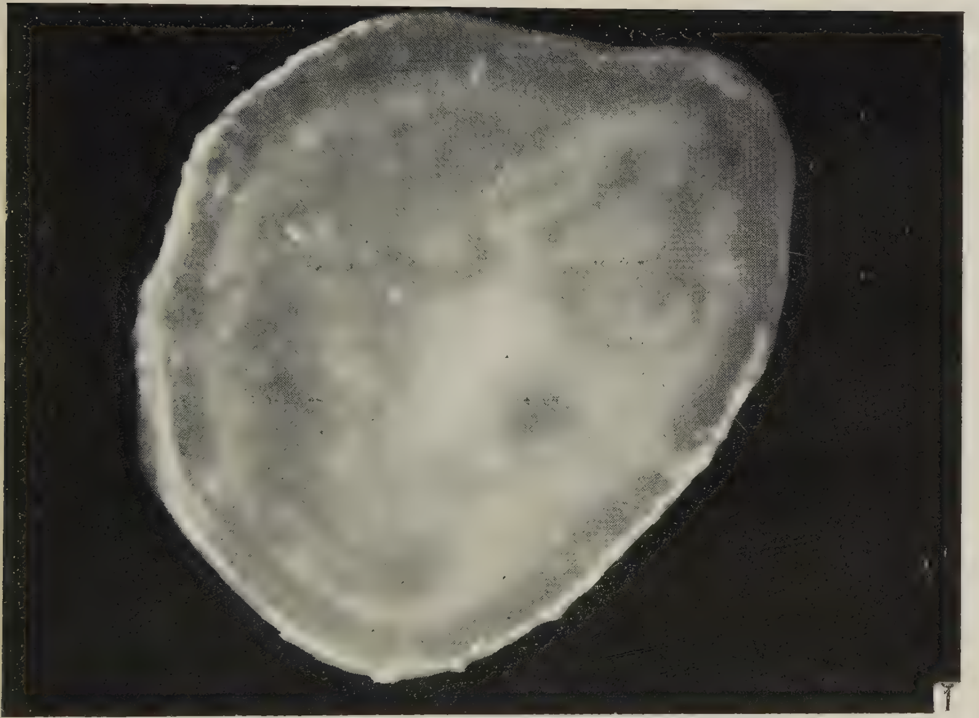
BLACKBURN.—THE TASMANIAN WHITEBAIT, LOVETTIA SEALI (JOHNSTON), AND THE WHITEBAIT FISHERY



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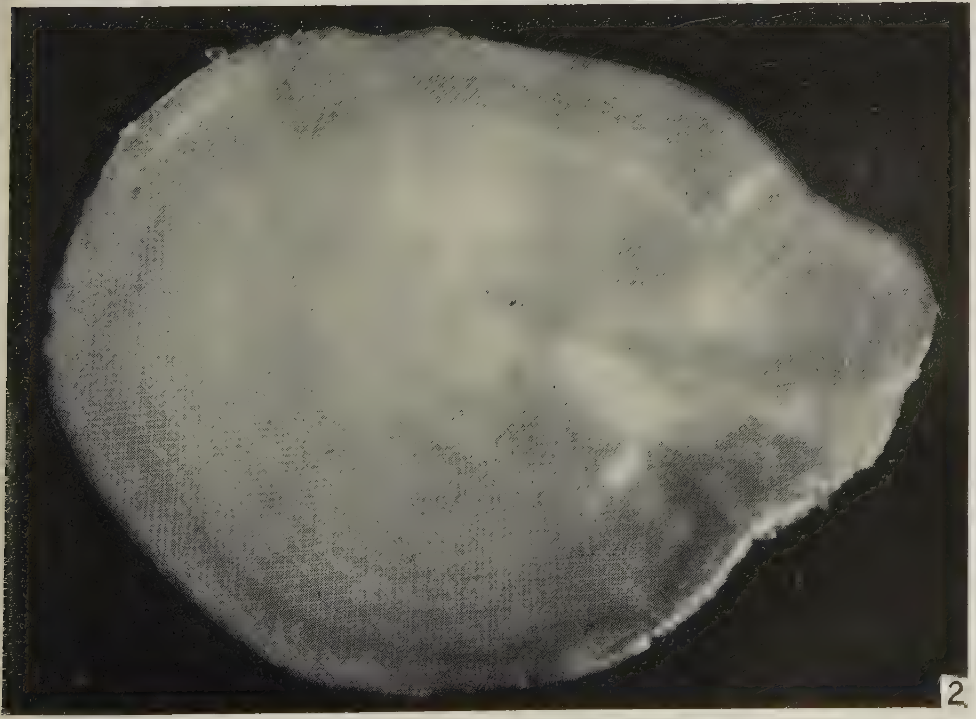

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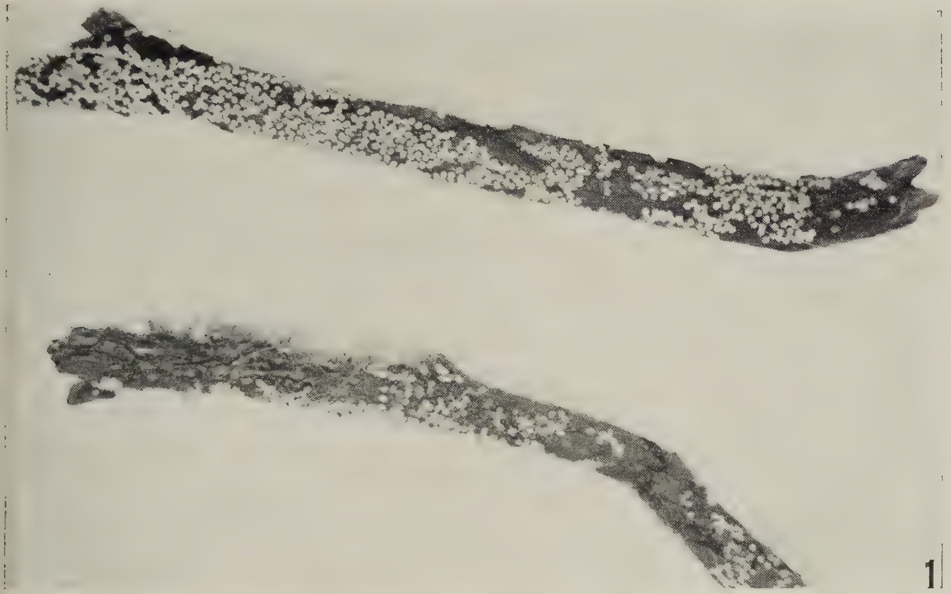

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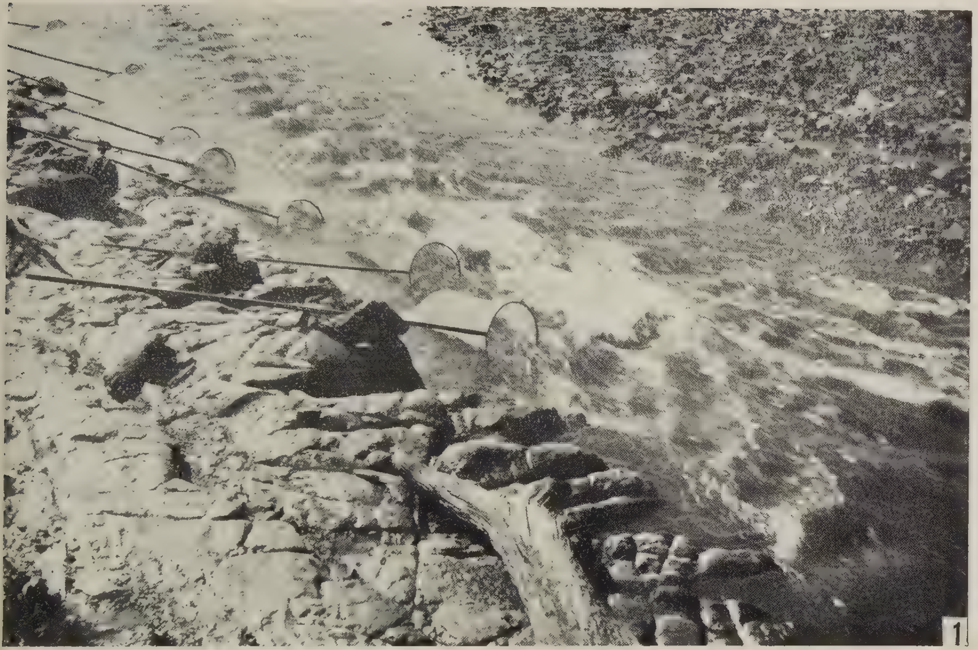

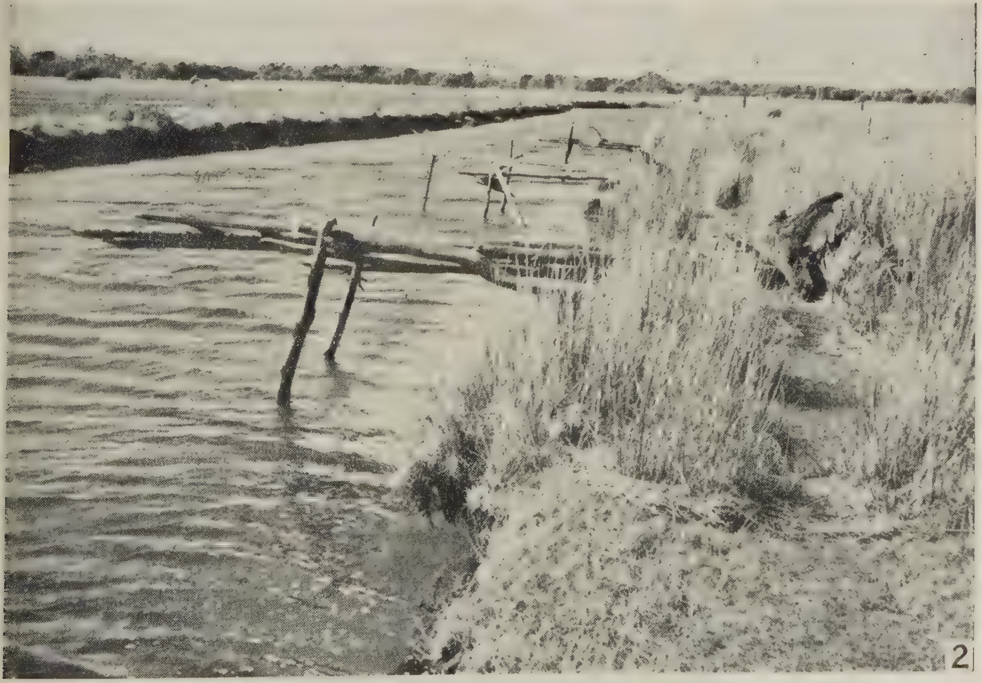

BLACKBURN.—THE TASMANIAN WHITEBAIT, LOVETTIA SEALI (JOHNSTON), AND THE WHITEBAIT FISHERY

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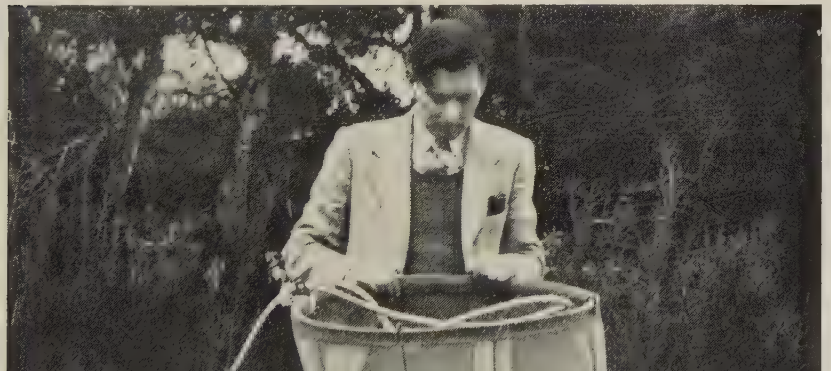
2

BLACKBURN.– THE TASMANIAN WHITEBAIT, LOVETTIA SEALI (JOHNSTON), AND THE WHITEBAIT FISHERY

was obvious that the canners would take increasing quantities of whitebait at an acceptable price (4d. per lb.), and the fishery then developed rapidly. Other streams were opened up to fishing, largely by the prospecting of bands of fishermen who moved from river to river, and by 1947 most of the larger north Tasmanian streams were being exploited. A few streams not listed in Table 12, including the Franklin River (see Fig. 2) and the Detention River and Crayfish Creek (between the Inglis and Black Rivers), were also fished to a very slight extent.

Whitebait are caught in scoop nets, which are very simple movable attended traps. Tasmanian fisheries regulations forbid the use of any other gear, and the licensing of scoops is compulsory. The original type of scoop is shown in Plate 4, Figure 2. It is a bag of ordinary fly-wire of 8 to 12 meshes to the linear inch, with the mouth attached to a circular frame at the end of a long staff. The scoop is lowered into the water so that the bag rests on the bottom. It is raised at intervals and emptied of the whitebait that have entered.

At first these scoops were used directly from the river banks, but this proved effective only where the water was fairly deep close to the bank, or in very narrow channels (Plate 5, Fig. 1). The next step was the erection of rough stages along the banks, which permitted the catchers to work in deeper water (Plate 5, Fig. 2). But it was obvious that the whitebait shoals were sometimes still further out from the bank, and many fishermen soon began to operate from boats, so that they could locate fish over a wider area of water. Plate 6, Figure 1, shows the boat fishery at the Leven in 1946: it indicates the intensity of the fishing effort, and the way all the boats habitually fall into line along the course the fish are following.

Plate 6, Figure 2, shows another type of scoop which is used only from boats, but which makes fishing possible in even the deepest parts of a river. The mouth of the scoop may be circular, semicircular, or square. The gear is lowered and raised with ropes, but is not towed. It first appeared in the Black and Duck River fisheries, which depend entirely upon boats because of the inaccessibility of the banks. By 1948 this net was displacing the other wherever boats were being used. The history of the northern fishery is therefore one of gradual improvement of fishing technique as well as continual extension to new areas.

The whitebait runs at Huonville are erratic, and the fish do not stay long in the same place, so that the northern fishing methods are not useful although boats are employed. Only staffed scoops are used, and they have to be raised much more frequently, which necessitates stronger gear and heavier labour. The shoals sometimes appear at the surface, as they also do in the north, but are then generally wary and hard to catch. These occurrences are usually associated with bright sunshine, and the fish may submerge if the sky becomes overcast. Night fishing has been tried in the north and south, but has never proved successful.

XIV. Condition of Stocks

Scoop licensing became compulsory in 1944, and the yearly numbers of licensed scoops measure the fishing effort. The effort in the north can only be described for the area as a whole, because of the movement of fishermen between rivers, but this is satisfactory because the northern whitebait population is homogeneous. In southern Tasmania the population is also probably homogeneous, and the numbers of scoops used in the different rivers may safely be combined. Table 12 shows the annual catch, number of licensed scoops, and mean catch per scoop, separately for the northern and southern areas. The full information for the north and the total catch information for the south are also given in Figure 5.

Table 12

TASMANIAN WHITEBAIT CATCH (LB.), NUMBER OF LICENSED SCOOPS, AND CATCH PER SCOOP (LB.) FOR NORTHERN AND SOUTHERN FISHING AREAS, 1941-1948

Year	North			South			Total Tasmanian Catch
	Catch	No. of Scoops	Catch per Scoop	Catch	No. of Scoops	Catch per Scoop	
1941	1,000			52,000			53,000
1942	—			46,000			46,000
1943	198,000			8,000			**206,000**
1944	187,000	242	770	19,000	25	760	206,000
1945	321,000	265	1,210	36,000	11	3,270	357,000
1946	750,000	485	1,550	24,000	14	1,710	774,000
1947	1,039,000	921	1,130	26,000	17	1,530	1,065,000
1948	325,000	743	440	23,000	11	2,090	348,000

There was a great decline in both catch and catch per scoop in the north in 1948, but the fall in the latter began in 1947. The possibility of stock decline was considered in the light of the 1947 figures, but it was felt that the change in catch per scoop might not be real, because of evasion of licensing of scoops in 1946 and earlier years. It is known that many scoops were used but not licensed in those years, though this factor was probably unimportant from 1947 onwards. The Tasmanian Sea Fisheries Advisory Board decided that no restrictive action should be taken in 1948.

In the light of the 1948 data it can scarcely be doubted that the lower catch per scoop of 1947 did indicate the beginning of a decline in abundance of fish in the northern rivers. The record total catch of 1947 was taken in spite of this because of the unprecedented amount of fishing effort employed. The scarcity of whitebait in the usual fishing areas in 1948 was remarked by everyone connected with the fishery. This probably caused the decline in the amount of gear licensed, as some fishermen do not normally commence work until the season is well advanced. The catch in every river was less in 1948 than in 1947, except for the Forester group of streams; here the 1948 catch was higher than that of 1947, but both were much less than that of 1946 (Table 11).

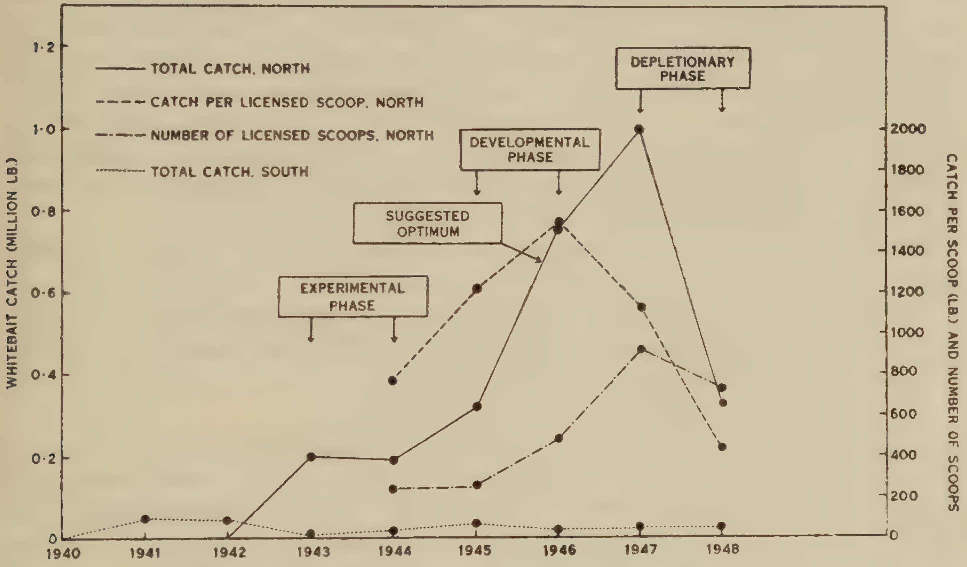

Fig. 5.—Total catch, number of licensed scoops, and catch per licensed scoop, for each year of the northern Tasmanian whitebait fishery, and total catch for each year of the southern fishery.

Decreased abundance in a population often results in increased growth rate of those present, because of lessened competition for food. There is some evidence that this has occurred with the northern stock of

TABLE 13

MEANS OF MEAN LENGTHS (MM.) FOR SAMPLES CONTAINING AT LEAST 100 FISH OF EACH SEX, FOR THE STATED STREAMS AND AREAS IN THE GIVEN YEARS; NUMBERS OF SAMPLES IN BRACKETS

Year	Sex	Huon	Black	Leven	Forth	Mersey	Other Northern	Total Northern
1944	♀	44.10(3)		45.54(8)		47.26(2)		45.88(10)
	♂	43.55(3)		42.18(8)		44.42(2)		42.63(10)
1945	♀	41.60(9)		44.98(3)	45.81(4)	46.16(1)	45.36(2)	45.50(10)
	♂	40.21(9)		42.26(3)	43.33(4)	43.92(1)	43.26(2)	43.05(10)
1946	♀	41.42(7)	46.89(3)	47.79(4)		48.55(5)	46.83(11)	47.38(23)
	♂	40.68(7)	43.35(3)	44.26(4)		44.85(5)	43.23(11)	43.77(23)

Lovettia. Table 13 shows the mean of mean lengths for samples containing at least 100 fish of each sex, for certain rivers in the years 1944, 1945, and 1946. The samples for the individual years are rather few, but the data for the north suggest variation in growth rate between year-classes rather than between rivers. The Mersey fish may be larger on average than those from other rivers, as some local observers believe, but their representation in the total north coast material of the different years is not such as would explain the findings simply on this basis. The mean size of males in the available samples regularly increased over the three seasons, while the 1946 average for females was higher than that of either of the other years. Bearing in mind the smaller numbers of samples for 1944 and 1945, there is a very definite suggestion that mean lengths rose between 1945, or even 1944, and 1946, and that the whitebait runs were correspondingly smaller.

The decline in the abundance of whitebait in the northern rivers might represent:

(*a*) natural fluctuation in availability, i.e. the fish might be present in their usual abundance but not in the fishing areas; or

(*b*) natural fluctuation in abundance; or

(*c*) depletion resulting from overfishing.*

A fluctuation in availability in the 1948 season has been suggested, but this would explain some only of the observations noted above and, in any event, the case is most unconvincing. Some fishermen stated that large shoals had been seen at sea or in the estuaries, and argued that these fish had been prevented from moving upstream by exceptionally heavy flows in the rivers. It was not proved that the shoals consisted of whitebait, or that they were really very large, and there was actually very little evidence, apart from observations on birds, that any shoals were present at all. It also seems certain that the river flows were not unusually heavy. The Commonwealth Meteorological Service monthly rain maps of Tasmania show that the August rainfall was below average over the entire area of the northern fishery, including watersheds, and that the September fall was also below average except east of the Tamar. In the "northern district" of Tasmania as recognized by the Meteorological Service, which includes the whole area of the northern fishery and stream watersheds, 14 weather stations reported some snow in the winter of 1948 as compared with 8 in 1947. However, in 1945 and 1946, which were good years for the whitebait fishermen, the numbers of stations reporting snow were higher, 28 and 16 respectively.

It is practically impossible to decide with absolute certainty whether a given decline in abundance of stock represents natural fluctuation or depletion. However, in this case, depletion is by far the more probable explanation. The following observations are pertinent:

(1) The fish have relatively low fecundity, spawn only once and then, if not caught, die naturally at the age of one year.

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* The decline cannot represent the fishing up of accumulated stock, as the stock is fully renewed from year to year.

(2) The fishery operates solely upon the spawning fish and especially upon those which have not yet spawned.

(3) The intensity of fishing has increased continuously and very rapidly from year to year.

(4) The decline in abundance as measured by weight of fish was evident in 1947, and the decline in numbers probably earlier, in 1946 or even 1945.

If depletion has occurred, the stock can be restored only by a temporary restriction of the fishery. If there is merely a natural fluctuation, the stock may recover without any restriction but the chances of its recovering would be better if there were some restriction to offset the added toll taken by the fishery. Whatever the cause, the fish were undoubtedly scarce in the spawning areas in 1948, which could easily result in the production of a numerically weak brood for fishing in 1949. If there were no restriction, it is thus far more likely than not that the stock would be reduced to the stage at which all fishing would be unprofitable.

Assuming depletion has occurred, the season in which the overfishing first took place was probably 1946, because the catch per scoop did not begin to fall until 1947 and the fish live for one year only. The suggestion of some reduction in numbers at an earlier stage does not necessarily imply overfishing, because of the compensating effects of greater size, and hence weight, of the individual fish, and of the increased fecundity associated with larger size. The mortality of eggs and larvae by cannibalism might also have been reduced. The catch of 1946 was therefore probably slightly excessive, while that of 1945 probably was not. Disregarding the effects of possible natural fluctuations in abundance or availability of stock, the optimum catch for the northern population must lie between the levels of 1945 and 1946, and probably closer to the latter. Unfortunately, the difference between the catches of these years is wide, so that even this empirical optimum cannot be accurately fixed. It is somewhat arbitrarily taken as 672,000 lb., i.e. 300 long tons (see Fig. 5), principally for the convenience of having a round figure for future management purposes. It should be the object of management policy to make the northern stock capable of again yielding that quantity year after year. Specific suggestions upon management are made in the next section.

It should be explained that, from the very beginning of the northern fishery, many people felt it should be severely restricted because of the likelihood of depletion. While it was recognized that depletion would probably occur, it was felt that restriction at such an early stage would be quite arbitrary and might result in permanent underfishing. Had the fishery been restricted in 1944 or 1945, as was suggested, what is now believed to be the optimum catch might never have been reached. In any case, it was then not known how many populations were involved.

The southern whitebait stock is obviously underfished. The catch per scoop averages (Table 12) are not comparable with the northern figures because of differences in fishing methods, and the part-time nature of the southern fishery. Whitebait were very plentiful in the Huon in 1948 and 1949. The data of Table 13 show no sign of increasing growth rate. Increased exploitation of this stock might be one beneficial result of temporary restriction of fishing in the north, and could enable canners to maintain supplies.

The history of the northern stock under fishing raises some points which are relevant to the general theory of fish stock management. Overfishing is any process of fishing which results initially (a balance, though not the best balance, can be restored if the rate of overfishing is stabilized) in the total removals from the part of a stock that is useful to man outweighing the total accessions to that part, in the biological year. The removals occur in two ways, by fishing mortality and natural mortality. The accessions generally occur in two ways, by recruitment of young and weight increase of survivors (Russell 1942, Chap. 4). In *Lovettia,* disregarding the minute proportion of the stock in the second age-group, the only accession is by recruitment. Therefore, if overfishing has occurred, it was purely by excessive removal of parent fish, resulting in diminished reproduction. Many fisheries biologists are far more concerned about the other kind of overfishing, which primarily reduces the growth of the stock in terms of weight. Some of them, while admitting that under-replacement is theoretically possible at an advanced stage of depletion, appear to think it would not often occur. These beliefs are held partly for reasons given below, and partly for lack of well-documented instances of curtailment of reproduction due to fishing. Ricker (1946, p. 384) could point to a few situations only where it seemed "very likely" that this had happened, and Huntsman (1944) did not know of one clear case in North America. The position with *Lovettia* is in doubt only to the extent that the finding of depletion may be questioned.

In Australia most fishermen and fisheries administrators think of stock management purely in terms of reproduction-potential, and great importance is still attached to legal minima based on lengths at which fish first spawn. As shown above, this factor is not so importantly regarded by many fisheries biologists. Their view is mainly based on the observation that tremendous losses of eggs and juveniles occur under even the most favourable environmental conditions, and that a direct relationship between size of parent population and resulting brood has not been found (references above). Graham (1948, pp. 31, 47-8) has given some account of the historical development of this idea, but he also pointed out that there is no crucial evidence about it. The northern population of *Lovettia* supported a significant fishery for a few years before there was any indication of decline in weight of stock, in spite of low fecundity and the fact that most of the fish caught would not have completed one spawning. If the optimum catch is 300 tons, then the yearly removal of nearly 100 tons of gravid females does not affect the yielding capacity of this stock.

It is concluded that the brood-stock of this population was in excess of that required to maintain recruitment and total stock weight in the early stages of the fishery, and that probably this exploitable margin was later overtaken, causing depletion. This contrasts on the one hand with the view of those who believe that it is essential for good stock management to allow every fish to spawn once, and on the other hand with that of some biologists who belittle the idea of conserving fish specifically for breeding. It is impossible to say which of these extremes is more nearly correct because the optimum catch, even if correctly estimated, is of unknown magnitude compared with the total stock. As already noted, the annual number of recruits may have been reduced at a relatively early stage in the history of the fishery, although temporarily without diminishing the weight and fecundity of the recruit brood at maturity. This rather suggests that the brood-stock surplus was relatively not very large.

XV. RECOMMENDATIONS FOR MANAGEMENT

The following recommendations were made to the Tasmanian Fisheries Division in March 1949, and were considered by the Tasmanian Sea Fisheries Advisory Board in July 1949. After a recommendation by the Board, the Minister for Sea Fisheries approved the implementation of the first proposal.

(1) The capture of whitebait should be totally prohibited in all rivers entering the sea on the north coast of Tasmania in the 1949 season.

(2) The total north coast catch should not exceed 100 and 200 long tons respectively in the 1950 and 1951 seasons.

(3) The total north coast catch should not exceed 300 long tons in each of the next two seasons.

(4) If a study of catch and catch-per-scoop trends then indicated that an annual quota of 300 long tons for the north coast could not be maintained, there should be experimentation with smaller quotas. If the conclusion was otherwise, the effects of larger quotas should be studied.

(5) There should be no restriction upon whitebait fishing in other rivers for the time being. However, if west or east coast rivers are exploited samples of the fish should be studied to see whether they belong to the north coast population (cf. Section X); if they do, the foregoing provisions should also apply to these and any intermediate areas.

It is important that the management system should be based on annual quotas, as suggested. The general level of the optimum catch is known, and should be the basis for the whole rehabilitation programme.

For a planned effort of this kind, the effect of any interim restriction must be known beforehand in terms of catch. Restrictions of the more traditional kind, e.g. merely prohibiting fishing in certain rivers or at certain times or by certain classes of men, may be found to result in a greater catch than is thought desirable.

It is suggested that whitebait buyers should make weekly statements of receivals to the local police, who would check them as to general accuracy from their own close observations on the fishery, and then submit them promptly to the Tasmanian Fisheries Division. As soon as the quota was complete all fishing would be prohibited for the rest of the season.

XVI. Conclusions

(1) *Lovettia seali* (Johnston), the principal species taken in the Tasmanian whitebait fishery, exhibits marked sexual dimorphism. The external urinogenital papilla of adult fish is far more anterior in the male than in the female, with a corresponding displacement of the alimentary and urinogenital systems. The larvae do not show these differences, and the intermediate stages are unknown. The males have longer pectoral fins and a significantly higher vertebral count in large samples.

(2) The species is anadromous and the spawning shoals ascend Tasmanian rivers in spring. In the north the season is broadly August to October inclusive, and in the south from mid September to mid December. The species has not been positively recorded from the west coast or the east coast north of Blackman's Bay (Dunalley), and is unknown beyond the Tasmanian mainland. At the fishing localities the chlorinity of the water is usually not more than 0.1 parts per thousand, but occasionally up to 1.2.

(3) The fish in the spring runs may have the gonads filling, full, part-spent, or spent. Full fish predominate at all the fishing areas except Huonville, where part-spents and spents are better represented. The latter stages are relatively ill-conditioned. The fecundity of females is positively correlated with their size, but the maximum number of ripe eggs recorded in a single fish is only 310.

(4) The extruded eggs adhere to submerged stones and timber and hatch in about three weeks. Larvae up to 7 mm. have been found in the plankton, and a downstream drift to the sea has been demonstrated.

(5) Length frequency distributions are of the normal type. The fish are thus virtually all of the same age, which according to otolith readings is one year. The minimum standard length recorded is 33 mm. and the maximum 70 mm., but all those over 60 mm. and some over 55 mm., representing 0.001 per cent. of the stock, are two years old. It is presumed that nearly all the fish die after their first spawning. The mean size of females is almost always higher than that of males of the same sample.

(6) The sex ratio of *Lovettia* is highly variable, but in a large material there were 225 males per 100 females.

(7) The development of black spots on the skin increases with succeeding maturity stages, the males being typically darker than females at the same stage. At Huonville the fish are so dark and lean as to be unacceptable for canning. This is because the fish reaching this area have mainly spawned in the downstream deltaic islet sector, where fuller and lighter-coloured fish are available.

(8) The *Lovettia* of the northern and southern fishing areas represent separate populations. The mean length of northern fish is greater than that of southern material of the same sex; the difference between mean female and male lengths is also greater in the north; and the southern *Lovettia* are typically more pigmented than northern fish of the same sex, at the same maturity stage. The northern population is homogeneous because the decline in abundance of *Lovettia* in this area in 1948 affected all rivers.

(9) Some *Lovettia* feed at all stages of maturity, the main diets being the eggs and fry of the species, mayfly nymphs, and amphipods. The species is preyed on by several kinds of fish and birds.

(10) Other fish associated with the upstream runs of *Lovettia* include the fry of *Galaxias truttaceus* (Cuvier), *G. attenuatus* (Jenyns), *Retropinna tasmanica* McCulloch, and gobies and atherines. These are also called whitebait, but over 95 per cent. of all Tasmanian fish marketed under that name are *Lovettia*. *G. truttaceus* fry can be found in the sea, which finally demonstrates the catadromous habit of the species.

(11) The southern Tasmanian whitebait fishery began in 1941 but has never been important because of the objectionable colour of the fish at the main fishing area, Huonville (but see (7) above). The northern fishery began in 1943 and developed rapidly, the catch reaching 1,039,000 lb. in 1947. Most of the fish are canned. The fisheries operate in the rivers on the ascending shoals.

(12) The northern whitebait catch fell to 325,000 lb. in 1948, and the mean catch per licensed unit of gear (scoop net) declined from 1,550 lb. in 1946 to 440 lb. in 1948. The scarcity of fish in 1948 was confirmed by all observers. Depletion resulting from overfishing is a likelier explanation than natural fluctuation in abundance, and fluctuation in availability can be discounted. The 1946 catch is therefore regarded as higher than the optimum, which is tentatively identified as 672,000 lb. (300 long tons). If depletion has occurred, it was due entirely to under-replacement of stock.

(13) It is recommended that the north coast rivers be closed to whitebait fishing in 1949, that catches for the four subsequent years should not exceed 100, 200, 300, and 300 tons respectively, and that there should then be experiments with higher or lower quotas in an effort to fix the optimum catch for the population more precisely. It is pointed out that canners

might maintain production in the meantime by encouraging the exploitation of the southern population.

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EXPLANATION OF PLATES 1-6

PLATE 1

Fig. 1.—Female Huon River *Lovettia*: a full fish at colour stage 2.
Fig. 2.—Female Huon River *Lovettia*: a part-spent fish at colour stage 4.
Fig. 3.—Female Huon River *Lovettia*: a spent fish at colour stage 4.

PLATE 2

Fig. 1.—Male Huon River *Lovettia*: a full fish at colour stage 2.
Fig. 2.—Male Huon River *Lovettia*: a part-spent fish at colour stage 5.
Fig. 3.—Male Huon River *Lovettia*: a spent fish at colour stage 5.

PLATE 3

Fig. 1.—Otolith of *Lovettia* 49 mm. standard length: Leven River, September.
Fig. 2.—Otolith of *Lovettia* 45 mm. standard length: Huon River, October.

PLATE 4

Fig. 1.—Deposited ova of *Lovettia*, Huon River.
Fig. 2.—Staffed whitebait scoop of northern fishery.

PLATE 5

Fig. 1.—Whitebait fishing from the bank: Rubicon River, 1946.
Fig. 2.—Whitebait fishing stages: New Great Forester River, 1948.

PLATE 6

Fig. 1.—Whitebait fishing with staffed scoops from boats: Leven River, 1946.
Fig. 2.—Improved whitebait scoop for boat fishing: Inglis River, 1948.

THE EFFECT OF A PERIOD OF INCREASED LEGAL MINIMUM LENGTH OF SEA MULLET IN WESTERN AUSTRALIA

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Summary

Following allegations of a depletionary trend in the mullet stocks a conservation scheme was initiated in Western Australia in 1942 by raising the legal minimum length in successive stages. In 1946 the legal length reverted to that in force before 1942. As far as can be seen from the catch statistics, the stocks did not benefit by the restriction period, the catches being of the same order before and after. It is possible that an increase in stocks occurred in the Shark Bay area, but as the fishery in this region was under-developed prior to the inception of the scheme there is no data to confirm such a supposition. The course of the Shark Bay fishery should be closely watched for any signs of overfishing now that the stocks are being more fully exploited. It would appear that no alteration in minimum lengths will effect an increase in the mullet stocks of the estuaries. There has been a definite decline in the mullet population of the Swan River since the early part of the century. This could be due to environmental changes rather than an effect of overfishing.

I. INTRODUCTION

The management of the inshore net fisheries of Australia has been effected by one or more of three control measures. Certain waters, usually in river or lake systems, are closed to commercial fishing on the grounds that they are either spawning and nursery areas or so confined that migrating schools of fish would be too completely captured. A second measure is to declare minimum legal lengths. In the absence of any data upon which an estimate of optimum catch may be based the criterion for establishing a minimum length is the early conservationist precept of permitting a fish to attain a size at which it would have spawned at least once before being captured. The third restriction, that of declaring minimum sizes of net mesh is designed to make effective the restriction on the take of undersized fish.

In the past, many of these restrictions have been imposed arbitrarily without regard to biological facts. Waters are often declared closed as the result of pressure from tourist and angling groups. Minimum lengths are frequently fixed below the breeding size because of commercial considerations.

Kesteven (1941) pointed out that sea mullet were being marketed in Western Australia at a size considerably below that at which this species breeds. The predominantly small size of the fish marketed from the main western estuaries was taken to indicate that "the catch is falling

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off and the stocks becoming depleted." Consequently protective measures were introduced by the State Fisheries Department in 1942. Much opposition was expressed by the majority of the estuarine fishermen. Finally, the conservation scheme was abandoned in October 1946.

The present state of the mullet stocks and the effects of the restrictions imposed are examined in this paper.

II. THE FISHERY

Strictly speaking there is not a mullet fishery in Western Australia, but estuarine and beach fisheries in which a considerable proportion of the fish taken are mullet. However, an elucidation of the features of such a mixed fishery can be achieved only by considering each species separately. Whatever the co-action of the various species may be, the effect of fishing will vary according to the peculiar biological characteristics of the particular kind of fish.

The sea mullet of Australia, *Mugil dobula,* is almost certainly conspecific with the world-wide *cephalus* as will be shown in a forthcoming publication by the author. In Western Australia this species is found from the western end of the Great Australian Bight to the region of Roeburne in the north-west (Fig. 1, blocks 2-66). Over most of its range other species of mullet occur. Some of these are confused with the sea mullet in the catch statistics but this is not important as they occur only over brief seasons or in certain specific areas. Thus the blue-tail or brown-back mullet (*Moolgarda pura* Whitley) is a tropical mullet, which, although ranging southwards as far as Shark Bay in late summer, becomes important only in the far north beyond Exmouth Gulf. Small schools of flat-tail mullet (*Mugil argenteus* Q. and G.) and sand mullet (*Myxus elongatus* Gthr.) are occasionally taken along the western beaches. However, the only other commercially important mullet, the yellow-eyed mullet (*Aldrichetta forsteri* (Cuv. and Val.)), which occurs over the south-western portion from the Bight to the Murchison River, is always distinguished as such in the catch reports.

The fish are taken by set nets or haul seine nets in the estuaries and by beach seines along the open coast. Full descriptions of the gear and methods of fishing are given by Kesteven (1942). A recent development is the use of ocean-going vessels over 60 feet in length from which dinghies equipped with beach seines can be sent where required. The vessels, with their own refrigeration, are used for reef fishing when not engaged in beach seining.

III. THE PRINCIPAL FISHING AREAS

The Department of Fisheries in Western Australia has devised a system based on that of California whereby for convenience fishermen's returns are referred to areas designated as blocks (see Fig. 1). The catch figures given in Table 1 reveal that there were seven of these blocks which produced over 10,000 lb. of mullet each in the years 1941 and 1947, which were respectively the years immediately prior to, and immediately after, the conservation scheme period. Six of these are common to the two years (blocks 6, 17, 18, 27, 28, and 37). The main fishing waters for mullet in these blocks are respectively the estuaries of Oyster Harbour, Wilson's Inlet, Hardy Inlet, Leschenault Inlet, Peel Inlet, and the Swan River. Block 29, the seventh of the 1941 group, includes the beaches between Bunbury and Fremantle, which are fished more thoroughly than any other beach in Western Australia. Block 15, which has become increasingly important, owes its development to improved accessibility and provides fish from a number of small estuaries and ocean beaches.

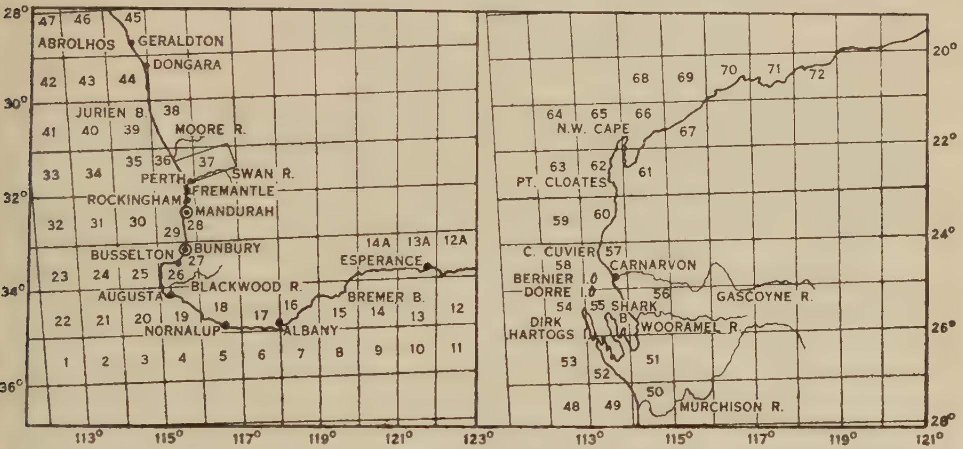

28°
30°
32°
34°
36°
ABROLHOS
GERALDTON
DONGARA
JURIEN B.
MOORE R.
PERTH
SWAN R.
FREMANTLE
ROCKINGHAM
MANDURAH
BUNBURY
BUSSELTON
AUGUSTA
BLACKWOOD R.
NORNALUP
ALBANY
BREMER B.
ESPERANCE
113°
115°
117°
119°
121°
123°
20°
22°
24°
26°
28°
N.W. CAPE
PT. CLOATES
C. CUVIER
BERNIER I.
DORRE I.
DIRK HARTOGS
CARNARVON
GASCOYNE R.
SHARK B.
WOORAMEL R.
MURCHISON R.
113°
115°
117°
119°
121°

Fig. 1.—Block index maps used in the Western Australian statistical system.

The south-western estuaries are small and shallow, without any apparent tidal flow (see Serventy 1938; Thomson 1946). Rainfall in this region is concentrated during the winter and all the river flow occurs during the rainy season. In normal summers the rivers cease to flow and dry up to a series of disconnected water-holes of varying size. The estuaries remain full of water only because they are drowned river valleys which are inundated by oceanic waters, and the salinity is approximately that of the sea. The winter freshets provide an almost complete freshwater scouring. The estuaries are thus unstable and consequently environmentally poor.

The upper river waters are closed to net fishing. Several of the smaller southern estuaries are closed to fishing permanently or opened only at rare intervals when fish are reported to be over-plentiful, e.g. Wonerup, Nannerup, Nornalup, Irwin's Inlet, and the Moore and Chapman Rivers.

In the northern sector of the State, only northern Shark Bay (block 55) provided an important mullet catch prior to 1942. In subsequent years a number of the neighbouring blocks extending to the north have developed into important fishing areas. The Shark Bay region is peculiar in that there are no rivers in the vicinity. It lies in a belt of poor rainfall and the only freshwater runoff occurs during the infrequent rains when temporary creeks discharge briefly. The Bay is about 80 miles long with a width varying from 10 to 35 miles. Sandy banks and shoals are abundant. In some seasons the water at the southern end of the Bay remote from the sea becomes higher in salinity than normal ocean water. The adjacent coastline outside the Bay has sandy beaches interrupted by long stretches of rocky shore. A fringing reef makes access difficult along much of the coast. Improved communications and the use of larger boats have brought about the increase in yield in this northern sector.

IV. Ecological Considerations

(*a*) *Environment*

Kesteven (1941, 1942) has shown that the sea mullet of various ages do not inhabit the same waters. The lower estuaries with water of a salinity only a little less than that of the sea are the favoured habitat of the immature mullet. The older fish move upstream to brackish or even fresh water. They do not occupy the lower estuaries except transiently during migration. The habitat grouping is sharply defined in south-western Australia as a consequence of the lack of tidal flow. The habitat of the younger mullet remains more or less constant in extent although subject to a great reduction in salinity during the winter floods. However, as has been described, the upper waters of the rivers are too limited in extent during the summer months to hold a large population. Large mullet do occur in the brackish and freshwater pools of the upper rivers, but they are few, even in the larger pools. Pools of sufficient depth to hold them safely through the summer are few, and any fish trapped in shallow pools are easy prey to aquatic birds.

(*b*) *Migration and Recruitment*

The mullet population of any one estuary is not a closed stock. Migration to, and from, the estuary can increase or diminish the population at any time of the year, except in those estuaries which at times are blocked from the sea by bars. In these cases, migration can occur only during flood periods when the bar is open. The bar of Peel Inlet at Mandurah closes sometimes but not every year. The bar of Wilson's Inlet closes nearly every summer. The southern estuaries east of Albany and the small rivers, such as the Chapman, in the vicinity of Geraldton, are nearly always closed by bars, opening for brief periods only.

Despite the tagging of several thousand fish, only one tagged mullet taken in a river system other than that in which it was tagged has come to hand. This was a fish tagged in Peel Inlet and recaptured 310 days later in the Swan River. Nevertheless, it is a matter of general observation amongst the fishermen that migration does occur (see Report of Select Committee appointed to enquire into the Fishing Industry. Government Printer, Perth, 1906).

A female mullet produces between one and three million eggs (Kesteven 1942). It is possible, therefore, that a small spawning stock inside the rivers could provide the population within the estuaries, but it is not believed that the estuarine population is an independent breeding unit. The object of the autumnal migration appears to be for spawning (Kesteven 1942). Faouzi (1938) and Arne (1938) have given evidence of a spawning migration to sea of the stocks of *M. cephalus* in Egypt and France respectively.

There is evidence to support a belief that *M. cephalus* can breed in coastal lagoons, etc., where the salinity approximates that of the sea (Belloc 1938; Dill 1944). Belloc, in describing successful breeding in Biguglia Lagoon on the east coast of Corsica, adds a note that the species does not breed in other coastal lakes into which large quantities of fresh water run. It is possible, therefore, that occasional breeding may occur in some of the barred estuaries. But the evidence is suspect as storms may cut temporary channels across bars, and floods open the bars of the remote estuaries without any witness to the event.

The only reliable reports of running-ripe female mullet come from ocean beach hauls in Shark Bay in Western Australia and Maryborough on the eastern Australian coast. A high proportion of 'whips' or spent fish are taken in these places at the end of the migration period.

Roughley (1916) favours the upper waters of the rivers as spawning places but his report seems more inferential than a statement of observed behaviour. Breder (1940) and Smith (1934) have reported what they regarded as spawning behaviour. However, attempts to take eggs in the vicinity were unsuccessful and the view of Kesteven (1942) that such phenomena consist of a pre-spawning rather than spawning behaviour seems most consistent with the facts. Professor J. L. B. Smith, in a personal communication, has informed the author that he has not been able to find any further evidence of mugilid breeding in estuaries and that he does not incline to this view.

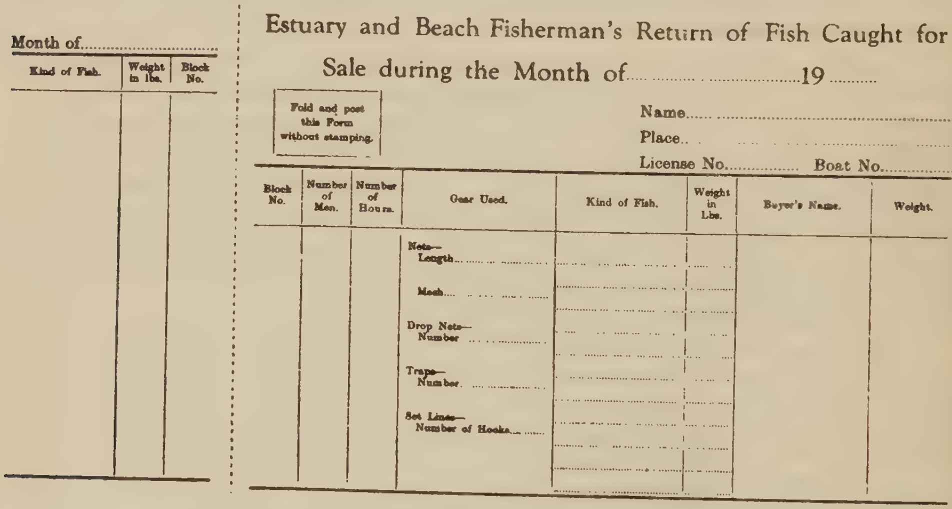
Whilst in Japan in 1948 the author had the opportunity to discuss the problem of mullet breeding with several Japanese authorities. They were unanimously of the opinion that they breed at sea. The Japanese scour their rivers thoroughly, taking even the smallest fish, and it is hardly conceivable that they would be mistaken in this observation.

It may be presumed, therefore, that the south-western rivers obtain their mullet recruitment from the sea, possibly from the large concentration of spawners found to the north. Whether the estuarine phase is obligatory for young mullet is not certain. Small fish of the I and II year-classes are sometimes taken in Shark Bay, so that it is possible the mullet of Shark Bay breed and remain all their lives at sea.

V. TRENDS OF CATCH

(*a*) *Reliability of Data*

The collection of fisheries statistics on a systematic basis was introduced into Western Australia only in 1941. The system has been described by Fraser (1943). At the time Fraser wrote, a single return form or 'log' was used for all types of fishing. Later a separate crayfish log was devised and in 1949 separate forms were introduced to distinguish the catches in bays and estuaries from those taken in the open sea. A page from the new bay and estuarine log is reproduced in Figure 2.



Month of..............................

Kind of Fish.	Weight in lbs.	Block No.

Estuary and Beach Fisherman's Return of Fish Caught for Sale during the Month of.............................19..........

Fold and post this Form without stamping.

Name..
Place..
License No................. Boat No.................

Block No.	Number of Men.	Number of Hours.	Gear Used.	Kind of Fish.	Weight in Lbs.	Buyer's Name.	Weight.
			Nets— Length....................				
			Mesh....................				
			Drop Nets— Number....................				
			Traps— Number....................				
			Set Lines— Number of Hooks..........				

Fig. 2.—Estuary and Beach Fishermen's Return form.

No centralized marketing is enforced in Western Australia. Economically it is probably inadvisable; but without such a check the statistical system is accurate only to the degree that fishermen are accurate in compiling their monthly returns. Despite the assurance that once the information is extracted the logs will be destroyed (Fraser 1943), a proportion of fishermen suspect their possible use by other agencies. It is generally accepted that Australian fish production is somewhat higher than fishermen's returns indicate (see "Fisheries Newsletter" 8(9):15). Nevertheless, the figures are undoubtedly of the right order though minimal.

Probably the least accurately reported section of the returns is that dealing with the time of fishing. At best the time reported is an estimate. Also it is difficult to compare the effort of a team using haul nets, where the haul lasts an hour or so at most, with that of a team which uses set nets which are not actually attended for hours at a time although the net fishes over the whole period. Therefore, it should be borne in mind firstly that the catch figures are minimal, and secondly, that the time factor introduces errors into the computations such that only gross differences have significance.

(*b*) *The Catch*

(i) *Annual Yield.*—The annual yield of mullet in Western Australia for the years 1941-1947 is shown in Table 1.

TABLE 1

WESTERN AUSTRALIAN SEA MULLET CATCH 1941-1947

Source: Fishermen's returns—State Fisheries Department. Units: pounds weight avoirdupois

Area	Block No.	1941	1942	1943	1944	1945	1946	1947
Irwins Inlet	5	4392	3110	440	30	1137	162	126
Oyster Hbr.	6	13029	9464	5485	5090	6415	5759	14975
Salmon Rocks	7	—	—	—	380	—	—	—
Recherche	12	—	—	—	—	—	—	120
Esperance	13	1957	—	1216	88	100	—	4359
Hopetoun	14	1927	—	—	88	953	8200	—
Bremer Bay	15	393	1664	—	6841	12225	27833	43529
Frenchmans Bay	16	2346	2230	600	910	151	149	1042
Wilson Inlet	17	10350	11457	1878	7290	8021	3078	12892
Nornalup	18	—	24	276	50	41	67	1044
Hardy Inlet	19	13551	19244	8031	9520	10403	11190	14798
Busselton	26	1532	1770	2157	392	1476	2678	1486
Leschenault	27	74226	20903	6980	9165	18355	10303	52389
Peel Inlet	28	112803	60049	23310	27139	92949	38274	44753
South Beaches	29	18276	4899	6294	5113	8171	4050	9004
North Beaches	36	9921	10812	18940	10235	13522	1593	8462
Swan River	37	67430	27030	21938	11695	23064	22399	41931
Moore River	38	—	—	—	—	145	290	1328
Jurien Bay	39	844	—	—	197	—	56	300
Dongara	44	501	1384	906	160	740	150	200
Geraldton	45	2774	1240	208	1314	2477	4071	64
Abrolhos	46	256	199	170	1254	1898	1732	204
Total south-west		336008	172459	178829	96951	202243	142934	352988
Murchison	50	—	—	2220	1020	1234	6256	17307
Hamelin Pool	51	—	—	—	—	4766	48093	3577
Denham Sound	52	5065	3301	855	2137	2433	72919	17171
Sth. D. Hartog	53	3515	300	154	—	216	—	—
Dirk Hartog	54	2474	2525	1103	1965	1290	—	—
Shark Bay	55	44046	71342	87087	86176	78996	190418	296196
Wooramel	56	—	—	—	520	2991	82184	46372
Gascoyne	57	—	—	—	—	17496	25845	9102
North-west Bchs.	60	—	—	—	—	—	2045	10470
Roeburne	66	—	—	—	—	4204	5262	18963
Total north-west		55100	80478	91419	91818	109232	427760	419978
Mullet, all areas		391108	252937	190248	188769	315679	575020	772966
Per cent. all species		13.6	11.1	8.0	6.0	7.6	12.2	
Min. legal length		9½ in.	10¼ in. (Mar.)	11¼ in. (Mar.)		9½ in. (Nov.)	11¼ in. (Feb.)	9½ in. (Oct.)

The decline in production over the years 1942 to 1945 is due in part to the decrease in the number of men engaged in fishing and in part to the increased minimum legal length which operated over this period. The effect of these factors will be considered in a later section.

A notable trend is the increased yield of mullet in the areas north of Geraldton. Little fishing was done in this region before 1940, and in 1941 the catch from the north-western areas was only one-sixth of that from the south-western region. However, by 1947 the yield of the northern areas was greater than that of the southern.

(ii) *Seasonal Catch.*—The monthly catches in the seven main producing areas over the years 1944-1946 are shown in Figures 3-9. In general, yield is greatest over the summer when the fish are gathered in feeding shoals. A minor peak in production occurs in early winter when the fish move down to the sea either to escape the floods or to embark on the spawning migration.

There is no regular level of catch in any one area, the amount of fish varying greatly from month to month. This fluctuation in catch depends to a considerable degree upon the weather. In the Shark Bay area the yield falls in midsummer when rough weather inhibits fishing. The catch in the southern estuaries decreases during late winter when rain is heaviest and flooding frequent.

(*c*) *The Fishing Effort*

(i) *Catch per Man.*—The variation in mullet catch over the years 1941 to 1946 cannot be attributed solely to the alterations in the minimum legal length shown in Table 1. A decline in manpower due to the wartime drain on the industry also contributed to the decline in catch. The reduction in manpower would tend to increase the catch per man by division of the same-sized stock among fewer men or by increased recruitment to the stocks following greater survival of fish to maturity (Graham 1939). However, in the present instance the coincidental raising of the minimum legal length is an opposing factor tending to decrease the catch per man by reducing the fishable stock, at least in the first year or so of the changed standard. Natural fluctuation in abundance is a third factor which might produce either an increase or decrease in catch. Unfortunately, as there exists only one year's record of the catch before the institution of the conservation scheme and the heaviest inroads upon the manpower of the fishing industry, there is no measure of the range of the normal fluctuation. There are, however, recognizable trends in the catch per man (Table 2).

The immediate effect of raising the legal minimum length in March 1942 seems to have been a lowering in the catch per man in the principal south-western estuaries except the Denmark River-Wilson's Inlet and the Blackwood River-Hardy Inlet systems (blocks 17 and 19). Any increase in catch per man that might have occurred due to the cut in manpower was evidently outweighed by the restrictive effect of raising the minimum length. The further raising of the minimum length in March 1943 brought about a further diminution in catch per man in most areas except in blocks 29, 36, 37, and 55. Blocks 29 and 36 are sea-beach areas where an increased catch of travelling fish is to be expected if a greater escapement from the estuaries is permitted. Presumably in block 37 (Swan River) either the drop in manpower more than compensated for the raised length standard or a natural fluctuation towards greater abundance occurred. In block 55 the great majority of fish taken are mature (three years and older) and larger than the highest minimum set during the conservation scheme (see Fig. 10). Consequently the alteration in the minimum length had no direct effect on the industry in this area.

TABLE 2

CATCH PER MAN AND NUMBER OF MEN 1941-1946

Catch units: pounds per man

Block No.	1941		1942		1943		1944		1945		1946	
	lb.	Men	lb.	Men	lb.	Men	lb.	Men	lb.	Men	lb.	Men
5	2196	2	1550	2	28	16	15	2	142	8	20	8
6	592	22	473	20	392	14	339	15	493	13	250	23
13	391	5	—	—	608	2	44	2	106	1	—	—
14	963	2	—	—	—	—	14	6	238	4	2050	4
15	196	2	832	2	—	—	1368	5	2445	5	3092	9
16	335	7	318	7	200	3	255	4	25	6	18	8
17	647	16	1432	8	626	3	561	13	501	16	205	15
18	—	—	12	2	138	2	25	2	10	4	6	11
19	2775	6	3848	5	2008	4	2760	4	1040	10	746	11
26	73	21	98	18	107	20	65	6	123	12	167	16
27	4366	17	1493	14	775	9	482	19	917	20	278	37
28	2302	49	1396	43	832	28	631	43	2266	41	736	52
29	192	95	136	36	331	19	568	9	908	9	579	7
36	180	55	721	15	1894	10	1023	10	676	20	177	9
37	3549	19	1802	15	2326	9	731	16	1099	21	1178	19
44	55	9	277	5	302	3	80	2	370	2	75	2
45	277	10	207	6	41	5	657	2	619	4	1357	3
46	16	15	19	10	17	10	627	2	316	6	577	3
50	—	—	—	—	444	4	510	2	345	3	2035	3
51	—	—	—	—	—	—	—	—	2383	2	5343	9
52	844	6	413	8	142	6	534	4	611	4	5609	13
53	502	7	75	4	26	6	—	—	54	4	—	—
54	225	11	252	10	138	8	327	6	645	2	—	—
55	2318	19	7927	9	7257	12	5386	16	6583	12	13601	14
56	—	—	—	—	—	—	176	3	498	6	6848	12
57	—	—	—	—	—	—	—	—	3499	5	5169	5
No. of men	395		239		193		193		240		293	

(ii) *Catch per Man-Hour.*—The catch per man-hour is available only for the years 1944-1946. The results of the earlier years (1941-1943) are not available as an undertaking had been given to the fishermen that the returns would be destroyed after the State Department had extracted the information which they desired (see Fraser 1943). The monthly trends for the principal mullet-producing areas are shown in Figures 3-9, while Table 3 shows the annual catch per 10 man-hours over these same three years. The outstanding feature to be noted is the much greater catch per unit of effort in the coastal fishery of the Shark Bay region (blocks 50-56) compared with that of the estuaries.

TABLE 3

CATCH PER 10 MAN-HOURS, 1944-1946

Units: lb. per 10 man-hours

Block	1944	1945	1946
5	3.3	6.9	1.2
6	16.9	15.2	6.5
7	3.7		
13	10.2	28.5	
14	3.1	12.2	51.8
15	9.5	19.0	39.9
16	7.2	0.6	1.4
17	11.0	4.6	4.1
18	6.4	0.4	0.6
19	8.7	14.7	11.3
26	8.2	7.7	4.2
27	12.0	10.9	5.5
28	5.6	15.1	9.6
29		0.2	3.5
36	6.6	10.7	4.1
37	11.3	8.2	13.7
44	5.7	7.7	4.4
45	7.2	4.4	8.8
46	37.3	8.1	4.3
50	28.3	15.6	27.1
52	22.7	20.7	27.9
54	22.5		
55	67.6	97.9	73.5
56	9.0	23.9	55.1

The seasonal and annual variations within any one block are presumably indicative of the trends within that block. But small differences between blocks are not significant owing to the errors derived from the time estimate. Inspection of Figures 3-9 reveals that there is great variation in the catch per unit of effort from month to month except perhaps in Wilson's Inlet.

Comparing Tables 2 and 3, it will be seen that the trends of catch per man and catch per man-hour are not identical in all cases. The errors in time estimation may cause this. On the other hand, if it can be assumed that the estimation of hours worked was of equal accuracy each of the years, then it appears that the catch per man, at least in ome cases, is not a good measure of the availability of mullet.

(*d*) *Effect of the Conservation Scheme*

(i) *The Control Measures.*—In March 1942, the minimum length of a mullet was raised from 9½ in. to 10¼ in. total length. In March 1943, e legal minimum was raised once more to 11¼ in. Following the commendations of Kesteven (1941, 1942) the minimum should have een raised again the following year, but strong representations from the shermen and other interested persons caused action to be withheld. Over e period November 1945 to January 1946, the old minimum of 9½ in. as permitted as a test period to gauge the effect of the closure. After liberating on the results the State Department reverted to the legal inimum of 9½ in. in October 1946.

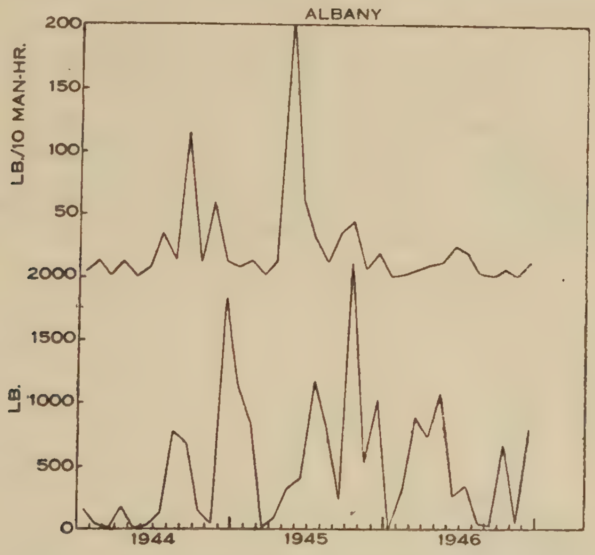


Fig. 3.—Monthly catch (below) and catch per ten man-hours (above), Albany area, 1944-1946.

The sudden drop in catch (Table 1) and catch per man (Table 2) icates that the restrictions were effectively observed. Undoubtedly a tain amount of undersized fish were sold through irregular channels but uantity equal to that indicated by the decrease in catch could not be rketed undetected.

(ii) *Expected Effect.*—The anticipated effect of the control was lt with by Kesteven (1941). Briefly "If the legal minimum lengths properly observed there may be some reduction in catch for a short riod, but after that the catch should improve year by year because the mbers of individuals in each age group will have increased . . . the mber, the weight and the value per man should be increased." Expressed ther way, if the fish are allowed to grow to a greater size a greater

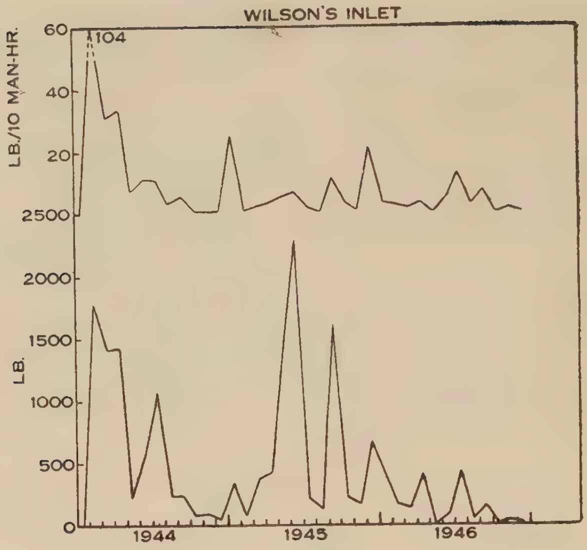


Fig. 4.—Monthly catch (below) and catch per ten man-hours (above), Wilson's Inlet, 1944-1946.

weight of fish would be taken and if there are more fish spawning there will be more young fish to enter the fishery.

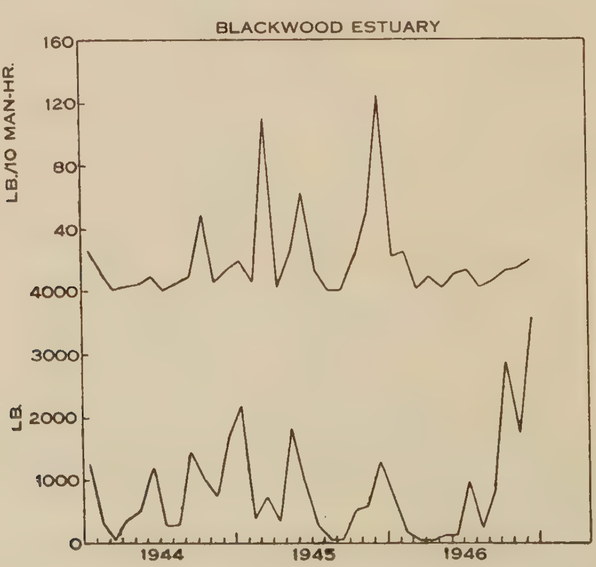


Fig. 5.—Monthly catch (below) and catch per ten man-hours (above), Hardy Inlet (Blackwood Estuary), 1944-1946.

Kesteven made no specific mention of where the anticipated numbe of older fish were eventually to be found. But it is evident that, lackin ny direction to the contrary, the fishermen and the State Department ook his remarks to apply to the fishery as then known, that is more or ss confined to the south-western estuaries. This is also implicit in an rticle which appeared in the Fisheries Newsletter (Anon. 1943).

It should be noted also that at no time did the legal minimum attain e breeding size as recommended by Kesteven. The greatest minimum gal length reached (11¼ in.) still includes only fish in their third year II+) whereas the mullet does not mature until its fourth year (III+). owever, the raised length would have the effect of deferring the time f year at which the II+ fish would be available to the fishery (Fig. 11). ith a minimum of 9½ in. the II+ fish could be taken all through the inter, but they would not attain a length of 10¼ in. until October nor 1¼ in. until December. These figures are means so that only half the opulation are at or greater than the mean size at the time mentioned.

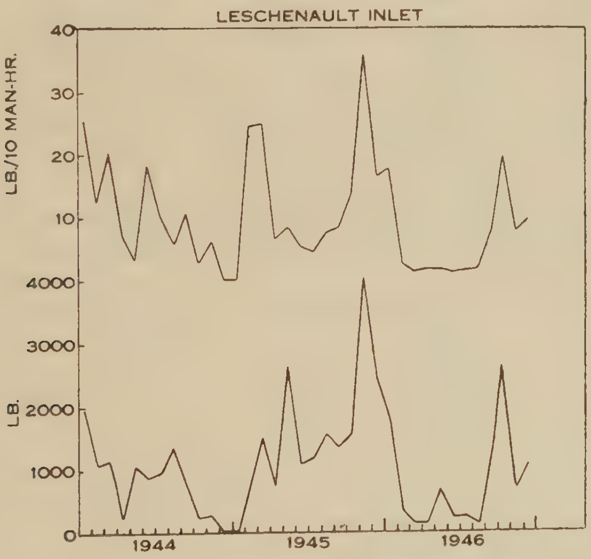


Fig. 6.—Monthly catch (below) and catch per ten man-hours (above), Leschenault Inlet, 1944-1946.

It has been mentioned (Section IV) that the older fish are not taken undantly in the estuaries. The size distributions for each area (Fig.) show that they were not taken in the estuaries to any extent prior to e introduction of the scheme in 1942 but they did occur predominantly the coastal fishery of Shark Bay. Therefore it is proposed to examine e effect on the estuaries apart from that on the coastal fishery.

(iii) *Effects in the Estuaries.*—Unfortunately, the Swan River is the ly one of the principal estuaries for which we have any data on mullet tch prior to the inception of the statistical system in 1941. In this area e mullet catch is now only a fraction of what it was at the turn of the ntury (Table 4).

There is only one estimate of mullet catch before 1900. If this may be taken as typical there would appear to have been an increase in yield following the decrease in the size of the legal mesh of nets in 1906. Several phases are discernible in the progress of the fishery from this period. Firstly, there is the period up to 1912 when the mullet catch was over 200,000 lb. and the catch per man over 5,000 lb. per annum, and mullet formed over 90 per cent. of the total estuarine catch. Then followed a second period, from 1914 to 1920, when the mullet catch dropped, generally being between 100,000 and 200,000 lb. with the mullet catch per man varying between 2,000 and 4,000 lb. and mullet contributing 70-80 per cent. of the total catch. In one year during this second phase, viz. 1918, the total catch, owing to increased manpower, returned to the level of the first period but the proportion of mullet and the mullet catch per man remained at the second period level.

TABLE 4

MULLET CATCH IN THE SWAN RIVER

Source: Annual reports, Western Australian Department of Fisheries

Year	Mullet (1000 lb.)	All Fish (1000 lb.)	Mullet (1000 lb./man)	No. Men	Legal Mesh	Legal Length
1899	123	280	38	32	3 in.	
1909	216	251	72	30	2½ in.	
1910	202	224	56	36		
1912	260	285				
1914	123	166	27	44		
1915	161	212	35	46		
1916	87	110	26	33		
1917	183	232	38	48		
1918	242	301	33	73*		
1920	73	95	22	33		
1921					2¼ in.	9½ in.
1941	67	171	35	19		
1942	27	260	18	15		10¼ in. (Mar.)
1943	22	214	23	9		11¼ in. (Mar.)
1944	12	182	7	16		
1945	23	199	11	21		9½ in. (Nov.)
1946	22	121	12	19		11¼ in. (Feb.) & 9½ in. (Oct.)
1947	42		30	14		

Mean catch/man 1914-1920, 3017
Mean catch/man 1941 and 1947, 3272

* Includes a number crabbing only.

There followed a period (1921-1940) during which no reports were made on the estimated yield of mullet. The size of the legal net mesh was decreased in 1921 to 2¼ in. What prompted this reduction and what the immediate effect on the fishery happened to be, is not known.

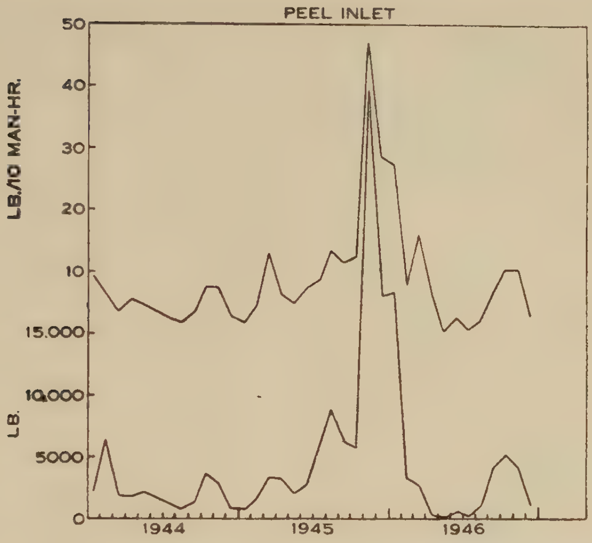


Fig. 7.—Monthly catch (below) and catch per ten man-hours (above), Peel Inlet, 1944-1946.

Lastly, we come to the years 1941-1947 for which some information exists. The number of fishermen was reduced owing to the drain of man-

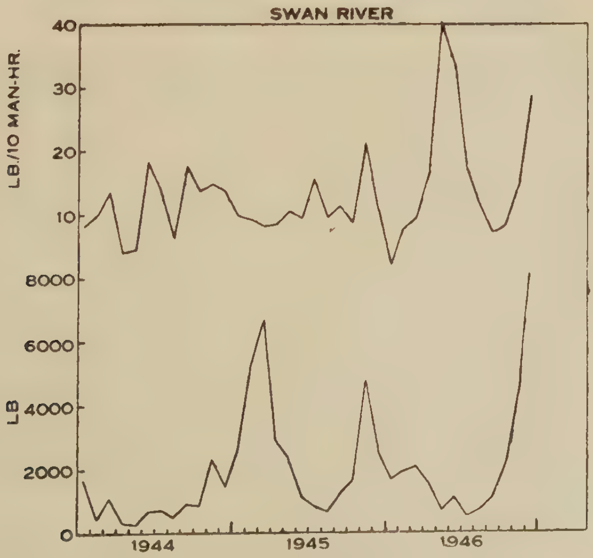


Fig. 8.—Monthly catch (below) and catch per ten man-hours (above), Swan River, 1944-1946.

ower to the Services. Consequently the mullet catch was lowered, though f 1941 and 1947 are considered as typical years under the legal standards which had held since 1921, then the catch per man was still of the same order as in the 1913-1920 period. But far fewer men were fishing in the later period for the same yield per unit of effort. Even in 1941, mullet was far less important an item in the catch than in earlier periods although the total catch remained of the same order.

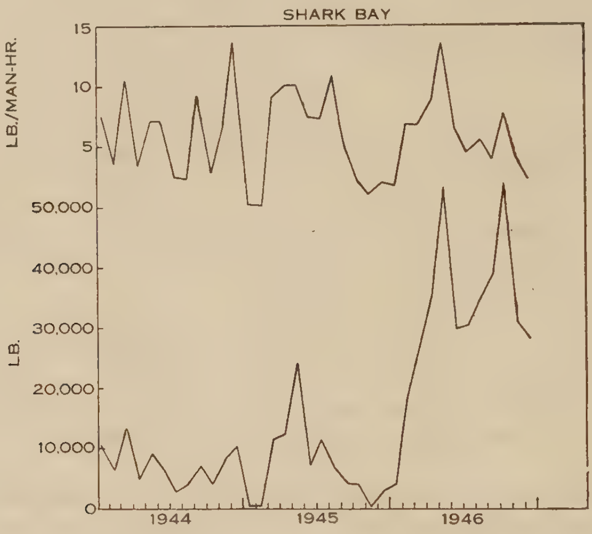


Fig. 9.—Monthly catch (below) and production per man-hour (above), Shark Bay area, 1944-1946.

The conclusion is inescapable that there has been a diminution in the numbers of mullet in the Swan River. This could mean overfishing and depletion. But, as Huntsman (1948) has pointed out, the same condition may be brought about by other factors. In estuarine and river fisheries particularly, action by man other than the operation of fishing may have considerable effects. Dr. D. L. Serventy of this Division, who has been investigating the history of the Western Australian fisheries, has informed the author that extensive swamp systems which formerly surrounded the upper Swan estuary have been drained since the early part of this century. Such brackish swamps are ideal feeding places for mullet. The shallows of the estuary where the smaller mullet typically feed have been largely eliminated by "beautification" schemes by which the shallows were filled in and the channels lined by stone bounding walls. This loss of important feeding areas must have had a considerable effect on the mullet-carrying capacity of the Swan River.

Kesteven (1941) has suggested that, as mullet form a substantial proportion of the total inshore catch, it is permissible to use the information on total catch to show what is happening to mullet. However, it is evident from Table 4 that it would not be valid for the Swan River except over very short periods. There would thus be no justification to use this method in considering the catch in other estuaries where some estimate of total catch exists although the mullet catch is unknown.

TABLE 5

MULLET CATCH, PEEL INLET, 1941-1947

Source: Fishermen's returns — State Department

Year	1000 lb.	Percentage of Total Catch	100 lb./Man	Legal Minimum
1941	112	28.7	23	9½ in.
1942	60	14.8	14	10¼ in. (Mar.)
1943	23	4.9	8	11¼ in. (Mar.)
1944	27	6.2	6	
1945	93	20.8	22	9½ in. (Nov.)
1946	38	17.9	7	11¼ in. (Feb.) 9½ in. (Oct.)
1947	44		11	

The effects of the restrictions imposed in the years 1942-1946 were similar in all three of the main western estuaries, Swan River (Table 4), Peel Inlet (Table 5), and Leschenault Inlet (Table 6).

TABLE 6

MULLET CATCH, LESCHENAULT INLET, 1941-1947

Source: Fishermen's returns — State Department

Year	1000 lb.	Percentage of Total Catch	100 lb./Man	Legal Minimum
1941	74	58.4	43	9½ in.
1942	21	16.2	15	10¼ in. (Mar.)
1943	7	6.8	8	11¼ in. (Mar.)
1944	9	9.5	5	
1945	18	9.2	9	9½ in. (Nov.)
1946	10	11.2	3	11¼ in. (Feb.) 9½ in. (Oct.)
1947	52		35	

There was a sharp reduction in the mullet catch and in the yield per man, while the proportion of mullet in the total catch fell considerably. The effect appears to have been more drastic in Leschenault Inlet than in the other two main estuaries. In 1942, the mullet catch in Leschenault Inlet fell by more than a third and the catch per man in about the same proportion. The further restriction in 1943 almost cut the figures in half again.

In 1944, the catch per man dropped still lower. There was an increase n the catch per man in 1945 but this was due to the increased catches in

November and December when the test reversion to a minimum length of 9½ in. took place. In Peel Inlet the rise was phenomenally large. In 1946, this increased level of catch was maintained only in the Swan River, the catch figure dropping in the other two estuaries despite the reversion to a minimum length of 9½ in. during January and again for the last three months of the year. The catch improved in 1947 but was less than that of 1941, the year before the conservation scheme commenced.

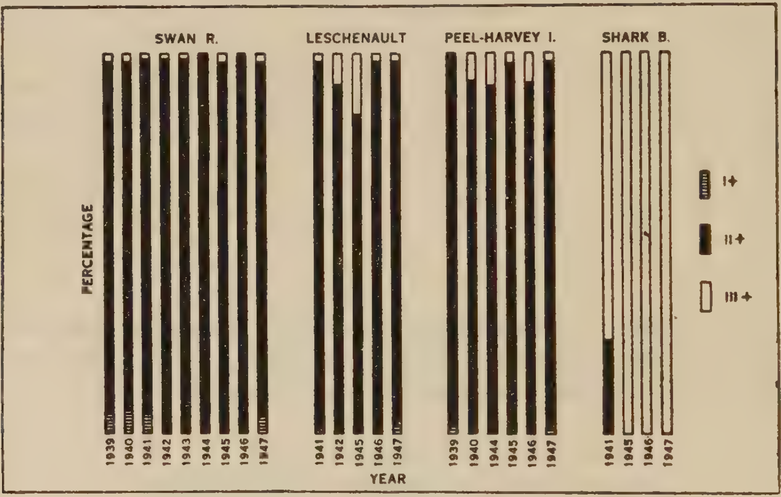


Fig. 10.—Proportion of age classes in commercial catch.

There were two possible effects of the restrictions upon the mullet populations of the estuaries: either the increased escapement of II+ fish should lead to a greater proportion of III+ and older fish in subsequent years and consequently an increased weight of fish taken; or if the older fish left the estuaries, those areas would still benefit by the increased numbers of younger mullet derived from this enlarged body of spawners.

It is apparent from Figure 10 that the proportion of older mullet in the estuarine catch did not increase, apart from an increment in Leschenault Inlet in 1945 which was not evident in any other year and so was presumably the result of some factor other than the size restriction. So the restrictions did not aid the mullet stocks by providing larger mullet in the estuaries, but in view of our knowledge of the distribution of mullet age-groups this was scarcely to be expected (see Section IV(*a*)).

The increased catch of 1945 was the result of the take of more young fish than in the previous year. In part, this was the result of the lifting of the restrictions in November and December, but the huge increase in Peel Inlet must also have been due to an increased number of young entering the fishery in that year. These fish would be the young of fish spawning in 1943, which were those escaping capture in 1942. But if the increased escapement in 1942 provided more offspring in 1945, then the still greater escapement of 1943 and 1944 should have provided even more young in 1946 and 1947. Actually, in these years the catch of Peel Inlet was much less than that of 1945.

When the minimum legal length finally reverted to 9½ in. in October 1946 there was an immediate increase in catch but equal or greater levels of yield were obtained during the restriction periods. Neither during nor after the restriction periods is there any evidence that the scheme benefited the estuarine populations. There was no consistent trend of increasing stocks. What evidence exists of population changes suggests that, if the scheme did have any effect on the population other than restricting the catch, it was masked by other factors producing natural fluctuations.

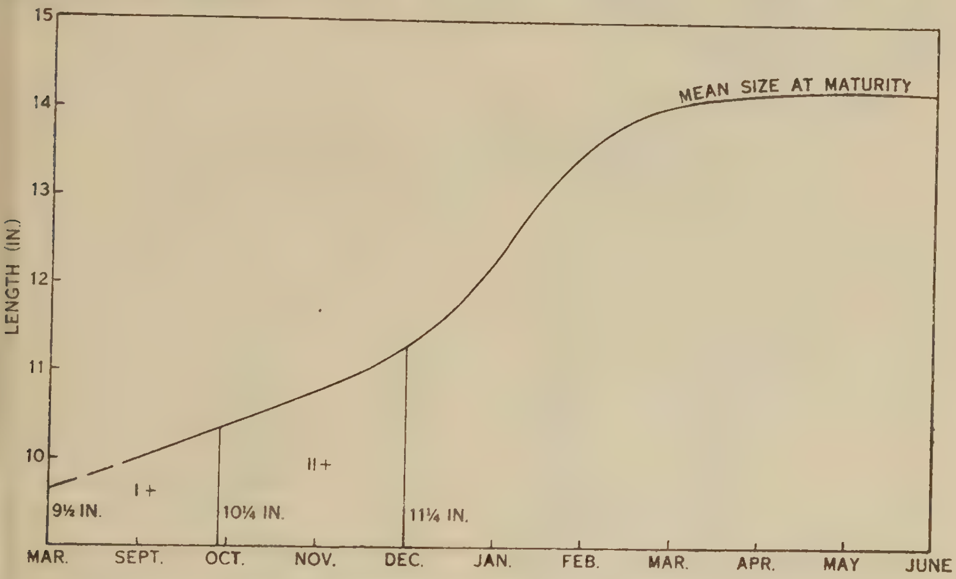


Fig. 11.—Seasonal growth of third-year fish.

The course of events in the minor southern estuaries can be traced in Tables 1 and 2 and Figures 3-5. The evidence again suggests fluctuations n population rather than any increase in weight or numbers of fish. The nly notable difference from the data for the main western estuaries is hat the catch in Wilson's Inlet and Hardy Inlet did not drop on the estriction to 10¼ in. in March 1942, but the further increase in minimum ength to 11¼ in. also affected these areas. Hardy Inlet exhibited a marked mprovement in the catch per man during the three months' lifting of estrictions from November 1945 to January 1946. But this effect did ot last as the catch per man remained at a low level when restrictions ere finally lifted (Fig. 5).

(iv) *Effects on the Beach Fishery.*—The fluctuations in the mullet ishery of the Shark Bay area do not seem referable to the effect of the onservation scheme. The catch increased over this period (Table 7), but the catch per man did not increase as regularly. There was a large increase in the catch per man in 1942, followed by fluctuating returns of between 5,300 and 7,900 lb., followed by another large increase in the measure in 1946 (Table 2, block 55). Over the years 1944-1946, when the mullet catch was increasing greatly, the catch per man-hour remained fairly constant. The test period of November 1945 to January 1946 had no effect on the Shark Bay catch, the poor weather ensuring that little fishing was done, and in any case no small mullet were being taken at that time (Fig. 10). The region was underfished before 1942 so that the catch figures are in no way a measure of the population of mullet. The catch per man increased very much after 1941 but, as has been mentioned, this is adequately explained by the more efficient methods of fishing adopted over recent years (Section III).

TABLE 7

MULLET CATCH, SHARK BAY AREA, 1930-1947

Source: 1930-1940 Shark Bay Supplies Limited; 1941-1947 Fishermen's returns — State Department

Year	Catch (lb.)	Year	Catch (lb.)
1930	22,367	1939	23,459
1931	2,200	1940	43,057
1932	7,200	1941	55,100
1933	11,795	1942	80,478
1934	44,269	1943	91,419
1935	36,590	1944	91,818
1936	17,725	1945	109,232
1937	14,227	1946	427,760
1938	22,647	1947	419,978

However, there remains the possibility that some portion of this increased catch was due to the increased escapement of mullet. It may well be that the large schools of mullet found at all times of the year around the Abrolhos Islands and Shark Bay are derived, at least in part, from the surplus mullet which leave the estuaries towards the end of their third year owing to the insufficient volume of upper waters in the rivers into which they could disperse. However, there is no direct evidence to support this hypothesis. As yet no fish tagged in the south-western estuaries has been returned from the Shark Bay area.

VI. STATUS OF THE FISHERY

The minimum legal length at which sea mullet may be marketed in Western Australia is below the size at which this species breeds. But as early as 1903, Petersen had pointed out that it was not necessary to ensure that all the fish of a particular stock spawn before they are killed. As the majority of commercial fish produce thousands or millions of eggs, if only a fraction survive to maturity the stock can still reproduce itself. The modern basis for the protection of young fish is to obtain the maximum weight of fish from any year group, in other words, to let any particular year group grow until it reaches the stage where the mortality rate (or removal from fishable waters) balances the rate of increase in weight due to growth.

There is evidence that the mullet population in the Swan River is less than it was fifty years ago. But raising the legal minimum had no noticeable beneficial effect on the mullet stocks in the estuaries. Raising the legal length did not alter the age composition nor add to the numbers of fish. Raising the minimum length to a size greater than that at first breeding would have a most adverse effect on the economy of estuarine fisheries. Whether it would result in an increase in the mullet production elsewhere, such as the Shark Bay area, is problematical and cannot be gauged from the data since full exploitation of the region coincided with the inception of the conservation scheme. After the return to the legal minimum of 9½ in. in the estuaries, the catch in the Shark Bay area should be watched for any signs of falling off in abundance as a result of the increased take of small fish in the estuaries. If heavy fishing on the adult stocks in such places as Shark Bay and the Bremer Bay area (block 15) should start a depletionary trend in these areas, then it might be necessary to review the position. If it should be proved that the big beach fisheries are dependent upon the estuaries, it might even pay to debar estuarine fishing on the young stocks. There is no evidence of such a trend at present.

The apparent failure of this management plan does not invalidate the theory upon which it is based, i.e., that a depleted stock can be restored by appropriate restrictions on the fishing. In this case depletion was presumed on inadequate evidence. The fact that the catches from the main fishing areas before 1941 consisted almost entirely of immature fish was interpreted to indicate a depletionary trend. But there is implicit in the ogic of this interpretation the assumption that the sampling provided an accurate picture of the age composition of the entire stock. Actually what was sampled was merely that portion of the population accessible to fishing within the estuaries.

Natural fluctuations seem to play a greater part in varying the catch from one year to another than any effect of fishing effort. The catch per unit of effort varies widely from one place to another and this seems to be in accord with the mullet-carrying capacity of the areas as there is no apparent correlation with the number of men fishing.

Biologically, there might be some improvement in the stocks if the egal minimum length was increased in Western Australia. But the ncrease would not appear in the estuaries. There is no evidence that he present policy on minimum size is producing a depletionary trend. Like most estuarine fisheries the sea-mullet industry is a low-level fishery and it would appear to be incapable of improvement within the estuaries. Indeed, any alteration to the existing fishery would be bound to have a considerable effect on the economic position of the men engaged in the estuarine fisheries.

VII. ACKNOWLEDGMENTS

Mr. A. J. Fraser, Chief Inspector of Fisheries and Game in Western Australia, readily gave access to the statistical data held by the Department of Fish and Game. Officers of his department, particularly Messrs. J. Gregory, A. Melsom, and L. Smith, assisted in the market measuring upon which estimates of age and size are based.

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STUDIES ON THE AGE, GROWTH, AND LIFE HISTORY OF THE PILCHARD, *SARDINOPS NEOPILCHARDUS* (STEINDACHNER), IN SOUTHERN AND WESTERN AUSTRALIA

By M. BLACKBURN*

(*Manuscript received February* 16, 1950)

Summary

The biology of the unexploited Australian pilchard, *Sardinops neopilchardus* (Steindachner), was studied from a limited material available from Victorian, Tasmanian, South Australian, and Western Australian waters. This completes the preliminary study of the species over almost the whole of its sub-continental range.

In Victorian waters, the surface shoaling season is spring and summer, in South Australia, summer and autumn, and in southern Western Australia, autumn and winter; these are the spawning seasons for the respective areas. In New South Wales and Queensland waters, the shoaling season is autumn to spring, which is again a spawning period. The situation in Tasmania, where the species is rare, is probably similar to that in Victoria. On the west coast of Australia, where the species extends northward to the Tropic of Capricorn (as it also does in the east) the seasonal distribution is not clear. In all these areas pilchard occurrences are virtually limited to the bay and neritic waters.

Victorian pilchards attain mean standard lengths of about 8.0, 10.5, 12.5, 14.0, and 15.5 cm. at the ages of one, two, three, four, and five years respectively. This growth rate is considerably lower than that in New South Wales. In southern Western Australia the growth rate is intermediate between the other two, but in South Australia it was not established. The average size of pilchards in the seasonal shoals appears to be greater in Western Australia than elsewhere, but no fish over 19.5 cm. standard length (9.0 in. total length) has been encountered in any of the current Australian investigations. Sexual maturity occurs earlier in Victoria than in New South Wales, sometimes at one year of age.

The ring pattern of Australian pilchard scales is complex, involving yearly, spawning, and secondary rings. A hypothesis to account for the formation of spawning rings is outlined, and an earlier hypothesis relating to yearly rings is abandoned. Secondary rings occur on most scales from the same fish. In all waters the season of ring formation coincides with that of surface availability of fish, but in Victoria it is also the growing season, which makes age determination particularly difficult. The fish-length/scale-length relationship for Victorian material is of the same linear type as for New South Wales, but there are differences in the size of scales taken from the same area of the body.

The possible influences of distribution, size, and condition of fish on future economic exploitation are discussed.

I. INTRODUCTION

The biology of the pilchard in eastern Australian waters (mostly New South Wales) has been reported (Blackburn 1941, 1949; Blackburn

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and Tubb 1950). Little was said about the species over the rest of its Australian range, which comprises the coastal waters of Victoria, Tasmania (in part), South Australia, and Western Australia south of the Tropic of Capricorn.

The present paper attempts to supply this information, in spite of difficulties arising from the lack of significant fishing operations, which also affected the previous studies. There is a very small fishery in Victoria which has yielded useful research material. Research vessel surveys and fishing experiments provided a moderate amount of data in Western Australia. In South Australia there was neither fishery nor sustained survey work, and the research material was relatively scanty. In Tasmania the material obtained was meagre in spite of efforts by research vessels comparable with those made in New South Wales and Western Australia, and it is concluded that the species is not abundant there.

This research has gone hand in hand with attempts to demonstrate methods of capture which would promote effective exploitation. That work has been successful (see Section VI) and the development of significant fisheries can be expected. Nevertheless, because of more immediately important tasks, the pilchard investigation is being concluded for the time being. It has already provided much more information than was available to those who started pilchard fisheries in other parts of the world. It may be resumed if sizeable fisheries emerge and encounter important problems.

II. The Pilchard in Victoria

(*a*) *Distribution*

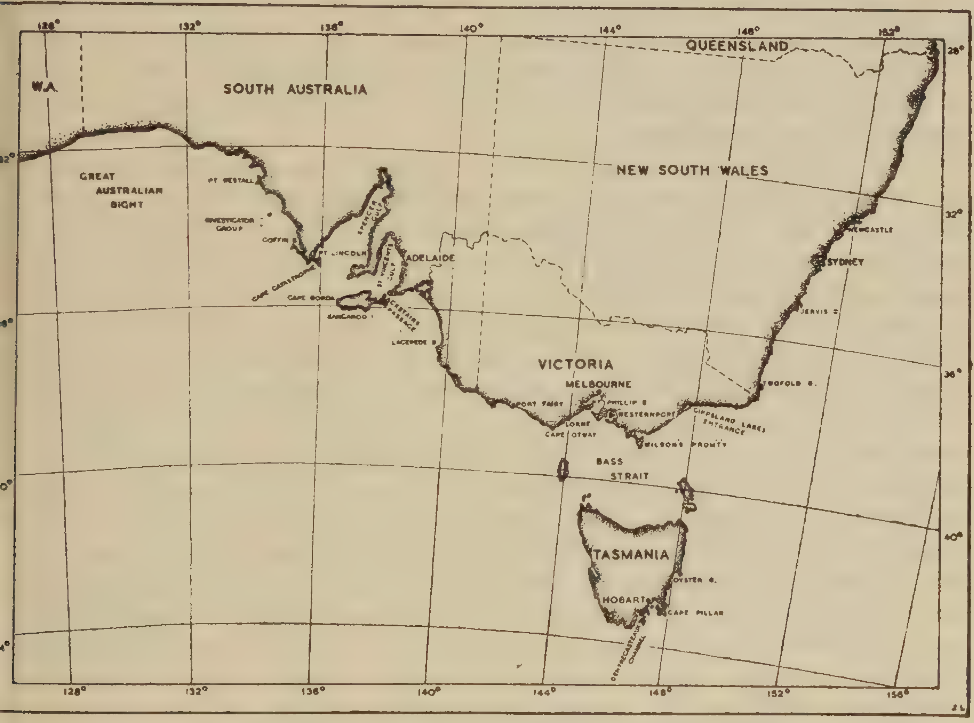
Regional and seasonal distribution was studied primarily from catches sent to the Melbourne fish market from Port Phillip Bay, Lakes Entrance, and Westernport (Fig. 1). This information was supplemented by enquiries made at those and other localities, and by research vessels.

The fishery is a mixed fishery for anchovies (*Engraulis australis*) and pilchards, the former predominating in the catches. Further particulars have been given elsewhere (Blackburn 1950, Sections III (*a*), III (*e*)) and newer developments are mentioned in Section VI of this paper.

Shoals of small fish occur off Lakes Entrance from about April to September or October, and at the Entrance itself until about January. The species composition of the shoals occurring from April to June is not known. Those of July and August consist of pilchards, anchovies, and sandy sprats (*Hyperlophus vittatus*) but, judging from the frequency of occurrence in the stomachs of barracouta (*Thyrsites atun*), the pilchard is the least numerous. From September to January some shoals come within range of beach seine nets, and pilchards are well represented in the catches of early spring. Towards the summer they are less plentiful, apparently as a result of seaward dispersion; the associated species move further up the lakes system and may be caught there until March (Blackburn 1950), but pilchards are seldom taken after January. The season of availability is therefore the spring.

Pilchard shoals have been reported by fishermen in the neighbourhood of Wilson's Promontory from July or August to January. Specimens have been taken in this area (Corner Inlet) in September.

At the entrance to Westernport, beach-seine catches of pilchards, anchovies, and blue sprats (*Stolephorus robustus*) were made from shoals which were plentiful from July to September 1945. Fishermen state that pilchard shoals also occur here in autumn.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SOUTH AUSTRALIA
QUEENSLAND
NEW SOUTH WALES
VICTORIA
TASMANIA
GREAT AUSTRALIAN BIGHT
PT WESTALL
INVESTIGATOR GROUP
COFFIN B.
PT LINCOLN
SPENCER GULF
ST VINCENTS GULF
ADELAIDE
CAPE CATASTROPHE
CAPE BORDA
KANGAROO I.
BACKSTAIRS PASSAGE
LACEPEDE B.
PORT FAIRY
MELBOURNE
PT PHILLIP B.
WESTERNPORT
LORNE
CAPE OTWAY
WILSON'S PROM'TY
GIPPSLAND LAKES ENTRANCE
TWOFOLD B.
JERVIS B.
SYDNEY
NEWCASTLE
BASS STRAIT
OYSTER B.
HOBART
CAPE PILLAR
D'ENTRECASTEAUX CHANNEL

Fig. 1.—Southern Australia, showing localities mentioned in text.

In Port Phillip Bay most of the fishing is done at Port Melbourne by oop-nets lowered from piers. The season is from October to March, specially the summer, and the fish are scarce over the rest of the year. each seine catches are sometimes made on the eastern shore of the Bay, nd indicate a similar seasonal distribution. However, pilchards have een found in winter in the stomachs of demersal fish such as sand flathead *Trudis bassensis*) and rock cod (*Physiculus barbatus*), and in meshing ets set at the bottom. Night fishing with purse-lampara and electric ghts resulted in several catches of pilchards from April to June 1948, nd the fishermen claimed that they could have taken the fish throughout the winter if they had been saleable. Small pilchards are found in the stomachs of barracouta off Port Phillip Heads in late spring, but fishermen say surface shoals are not common in this area. The Port Melbourne fishery is more subject to significant fluctuations than that for anchovies at the same locality: the seven seasons 1942/43 to 1948/49 included three successive years in which pilchards were scarce, and notable variations occurred in previous years (Blackburn 1950, Section III (*e*)). However, pilchards are sometimes reported from other parts of the Bay when they are not at Port Melbourne.

Small pilchards have been found in stomachs of barracouta taken off Lorne and Port Fairy in late spring. To the west of Westernport, surface shoals of pilchards appear to be uncommon in the open sea at any time of year. Reconnaissances by research vessels and aircraft have yielded no results, and many reliable fishermen have stated that such shoals are rare in western Bass Strait.

On the New South Wales coast the season of maximum abundance of pilchards in surface waters is progressively later, from autumn through winter to spring, towards the north (Blackburn 1941, pp. 37-9; Blackburn and Tubb 1950, p. 26). The foregoing observations indicate that the season in Victoria is later towards the west, occurring in spring at Lakes Entrance and in summer at Port Phillip. In New South Wales the season is also the spawning season, and, as shown by the distribution of eggs and larvae, this is likewise later towards the north (Blackburn 1941, pp. 37-9). The same relation applies in Victoria, although it is better shown by gonad maturity stages (see Section II(*c*)). The seasonal distribution of eggs and larvae is well established only for Port Phillip, where hauls have been made with the "Discovery" N70 plankton net in several parts of the Bay at all times of year, in different years. Eggs were found from late September to late January, especially from late October onwards, but not at other periods. The best catch was 40 eggs in a 15-minute surface haul. The best catch of anchovy eggs in Port Phillip was about 3,000, taken at the same time of year with a similar haul with a smaller net (Blackburn 1950, p. 15). The average catches of eggs of the two species were in similar proportion.

Many plankton hauls have been made in Gippsland Lakes from September to January in different years, but none yielded any pilchard stages. As it is shown in the next section that these months cover the spawning season at that locality, spawning apparently does not take place in the inlet. Eggs and larvae have rarely been found in plankton taken in Victorian open sea waters. A 15-minute N70 surface haul off Wilson's Promontory in November 1948 took 430 eggs, but there was none in similar hauls at six other stations on various parts of the Victorian coast in the same month. Hauls made at eight representative stations from January to March and again from September to October 1949, and at three stations in June 1949, did not yield any pilchard material.

(*b*) *Size*

All pilchards in the samples from Victoria and elsewhere were measured for standard (body) length, i.e. excluding the caudal fin. Total length, i.e. from snout tip to the end of the longest caudal fin rays in their most extended position, is approximately 1.17 times standard length (Blackburn 1949, p. 72). Appendix I gives particulars of samples contributing to the total of 6,369 measured Victorian fish, which were obtained from Port Phillip, Lakes Entrance, Westernport, and Corner Inlet near Wilson's Promontory. The fish in a given sample were usually very uniform in length, and from 100 to 200 was generally found to be an adequate sample. The practice was to obtain one monthly sample of each size-group from each locality, when pilchards were available in the market, but, as the fishery is very small, there were many months in which no samples were procurable. Lengths mentioned in this paper are standard lengths unless otherwise stated.

Figure 2 shows length frequency polygons for the material of each locality represented in each month (excepting June with only 15 fish), irrespective of year of collection. This gives some idea of the general size composition of the stocks available to the existing fishery. The largest specimen, from Lakes Entrance, measured 183 mm., or 8.4 in. total length. The modes in the polygons are distinct, but most of them could not be identified by age from the information of Figure 2 alone. They have mostly been so identified by scale studies on the samples in question, and this is indicated in the figure. The progression of I-group modes shows that the growing season is in the warmer part of the year. It lasts at least from September to January, and is thus broadly identical with the season of growth in the pilchard in New South Wales (Blackburn 1949, Section II) and the anchovy in Victoria (Blackburn 1950, pp. 33-6). In those fish very little increase in length occurs in winter, except in the O-group.

(*c*) *Maturity*

In previous pilchard studies it proved difficult to distinguish between certain gonad maturity stages (Blackburn 1949, pp. 59-60). The matter has received much further study, but many difficulties remain with male fish. The criteria for the different stages are as follows:

Female

Stage 1.—Obvious immatures. Ovaries less than two-thirds (usually less than half) of body cavity length, very thin ribbons tapering somewhat posteriorly, transparent or pale yellow.

Stage 2.—Ovaries more than two-thirds of body cavity length, ova not clearly discrete as seen with the naked eye; pale yellow in fish maturing for the first time, often partly bloodshot in recovering spents.

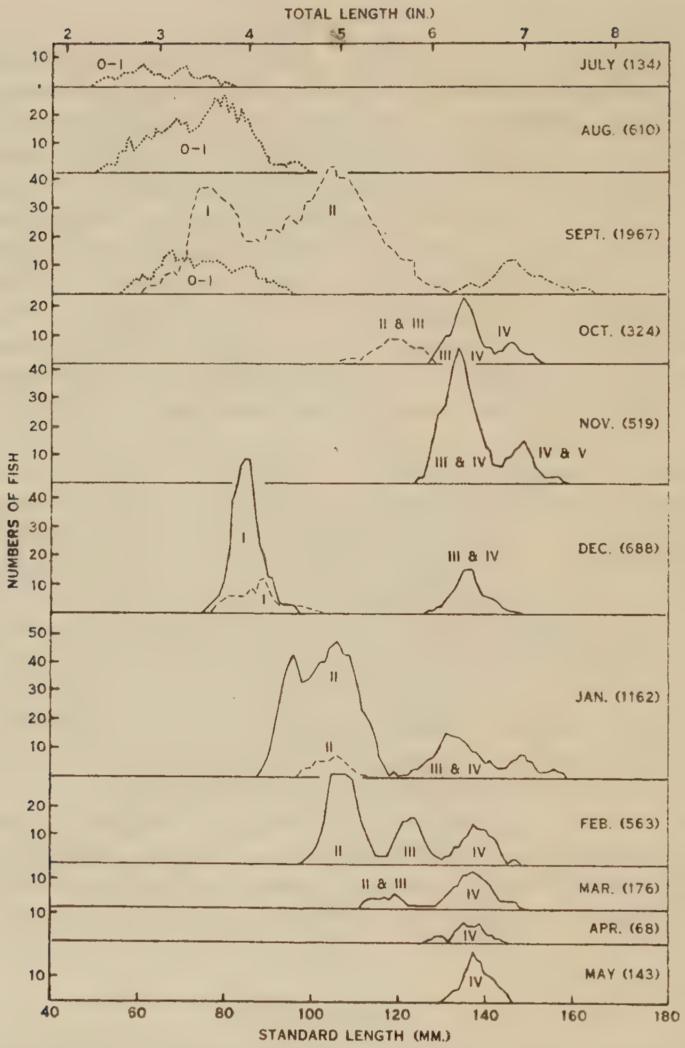

Fig. 2.—Length frequency polygons for samples of Victorian pilchards taken in successive months, material of all years combined. Curves are smoothed by a moving average of three. Roman numerals indicate ages, as determined from scale readings, at the lengths indicated. The monthly specimen totals (all localities) are shown in brackets. Polygons outlined ——— are fish of Port Phillip Bay, — — — Lakes Entrance, ... Westernport, and —.—.—. Corner Inlet.

Stage 3.—Ovaries full length of and half filling body cavity, yellowish-brown, pigmented eggs clearly discrete.

Stage 4.—Ovaries about two-thirds filling body cavity.

Stage 5.—Ovaries maximum size, almost filling body cavity.

Stage 6.—Usually represents running ripe fish in such classifications, but has not been seen.

Stage 7.—Obvious spents. Ovaries about three-quarters of length of body cavity, flaccid and shrunken, generally very bloodshot, often with a few large yellowish residual ova. Succeeded by stage 2 (recovering) with which there is overlapping. Part-spent ovaries, with many large ova remaining anteriorly, are occasionally found.

Male

Stages 1 *and* 2.—Recognition of these presented the same difficulties as in the anchovy (Blackburn 1950, p. 11). The smallest testis is less than one-quarter of body cavity length, rather leaf-like, and transparent. This stage intergrades closely with others in which the testes are still very small in bulk but up to two-thirds of body cavity length, and sometimes opaque white. Any distinction would be arbitrary, and some of the smallest testes observed were semi-bloodshot and obvious recovering spents. As the red coloration is variable and finally disappears, and is often particularly questionable in preserved material, there is no reliable criterion for immature males.

Stages 3, 4, and 5.—Testes white, full length of body cavity, distinguished by bulk as for corresponding female stages.

Stage 6.—Not seen.

Stage 7.—Obvious spents. Testes about one-third to one-half body cavity length, flaccid, shrunken, and bloodshot. The leaf-like shape may be disguised by crumpling.

At Lakes Entrance, stage 5 fish were found in October and December, and stage 7 in September, October, and December. There were very few August and no November specimens available for study, but those taken in January included neither stage. At Port Phillip, stage 5 was found in November, December, and January, and stage 7 in all months from October to May. Few September or June specimens were available. Obviously, the spawning season is broadly identical with that of greatest abundance at each locality (see last section), and is later at Port Phillip than at Lakes Entrance.

For investigating length at first maturity, observations on gonad stages of Lakes Entrance and Port Phillip females are available. The corresponding observations on males are not reliable for this purpose. The peak of the spawning season at each place is taken as the period at which stage 5 occurred, although this may be somewhat early. Table 1 shows the proportion of specimens of each half-cm. length-group which had or would have spawned in the current season, i.e. which were at stages 2-7. References in this paper to half-cm. length-groups use the figure beginning the group, e.g. 10.0 cm. = 100-104 mm. and 10.5 cm. = 105-109 mm., inclusive.

Table 1 suggests that most females mature at lengths above 8.0 and 10.0 cm. at Lakes Entrance and Port Phillip respectively. The tabulated Port Phillip data for sizes under 10.0 cm. are scanty, but there was one large sample of such fish (mainly 8.0 and 8.5 cm.) which certainly contained many females although sex was not recorded, and which were all at stage 1. This also applied to a sample containing many fish at 10.5 and 11.0 cm., and the mean length at first maturity at Port Phillip is thus probably higher than Table 1 would suggest. Applying the general conclusions of Section II (*d*) (iii) regarding age-for-size, and the age determinations for the individual samples represented in Table 1, it can be stated that one-year fish are often mature at Lakes Entrance but rarely, if ever, at Port Phillip; while at two years almost all fish at Lakes Entrance are mature, but some at Port Phillip are not. The position in New South Wales is similar to that at Port Phillip (Blackburn 1949, p. 60).

TABLE 1

NUMBERS AND PERCENTAGES OF LAKES ENTRANCE AND PORT PHILLIP FEMALE PILCHARDS MATURE AT SUCCESSIVE LENGTHS, IN OCTOBER TO DECEMBER AND NOVEMBER TO JANUARY RESPECTIVELY

Length (cm.)	Lakes Entrance			Port Phillip		
	Total	Mature	%	Total	Mature	%
7.0	2	1	50			
7.5	1	1	100			
8.0	10	9	90	1		
8.5	12	11	92			
9.0	6	5	83	1	1	100
9.5	5	5	100	1		
10.0	3	3	100	10	8	80
10.5	2	2	100	27	27	100
11.0	1	1	100	10	10	100
11.5	15	15	100			
12.0	16	16	100	2	2	100
12.5	9	9	100	17	15	88
13.0				74	69	93
13.5				76	75	99
14.0				37	34	92
14.5				22	21	95
15.0				9	9	100
15.5				2	2	100
16.0				2	2	100
16.5				1	1	100

(*d*) *Age Studies with Scales*

(i) *Treatment of Material and Data.*—In this study, 5,510 scales, obtained from the mid-flank sub-dorsal region of 1,382 Victorian pilchards, were mounted and read. This body area was the same as that from which scales were taken from New South Wales fish (Blackburn 1949, pp. 26-7). Scales were also examined from other parts of 20 fish.

The scales were cleaned and mounted as in previous clupeoid investigations (Blackburn 1949, p. 25, and 1950, p. 17). From one to six scales from each fish were mounted, and fish-length (L) in mm. and usually the sex and maturity stage were recorded. The scale-reading method was that of the previous pilchard study (Blackburn 1949, p. 25; see also Kesteven and Proctor 1941), but the magnification and intermediate lengths (L_1, L_2, etc.) were recorded only for the most legible mounted scale from each fish. The scale dimension (S) was obtained in mm. by dividing L by the magnification. The recording of intermediate lengths involved the assumption of a direct-proportion relationship between L and S. However, that does not apply in this material, and the L_n values had to be corrected.

Table 2 gives means of L and S for each half-cm. interval of L, separately for the material of Lakes Entrance (300 fish) and Port Phillip (988 fish). The regression equations were

$$L = 15.79 + 29.94\,S \text{ (Lakes Entrance), and}$$
$$L = 16.79 + 27.67\,S \text{ (Port Phillip).}$$

The regression lines are shown in Figure 3, together with that for New South Wales material (Blackburn 1949, p. 28), which was

$$L = 14.77 + 32.91\,S.$$

Figure 3 shows that the scales of the pilchard tend to be larger towards the south in eastern Australia, although the trend is opposite to this in the anchovy (Blackburn 1950, pp. 52-3). However, the L/S relationship is always linear and the intercept constants, which are involved in correcting the L_n values, are similar in the three equations. A value of about 15-17 mm. for this constant is clearly characteristic of the L/S relationship for these scales in the pilchard of south-eastern Australia, and it may safely be concluded that it would not differ greatly in regression equations that might be calculated from adequate material of different year-classes at the same locality. This is important because the available material was not adequate for such calculations. The same difficulty was encountered in the New South Wales pilchard study (Blackburn 1949, pp. 43-4), and the conclusion reached there, that differences between the material of different year-classes were unimportant for correcting L_n values, is actually much better supported by the present observations than by those in the earlier paper.

The combined data for the two Victorian localities yielded the regression equation

$$L = 16.15 + 28.00\,S.$$

The intercept constant 16 was used to correct all L_n values from scales from both areas, and from all intermediate localities. This accounted for the whole Victorian material. It has been shown elsewhere (Blackburn

TABLE 2

MEANS OF SCALE-LENGTHS (S) AND CORRESPONDING FISH-LENGTHS (L), FOR SUCCESSIVE HALF-CM. INTERVALS OF L, FOR ALL AVAILABLE MATERIAL FROM LAKES ENTRANCE AND PORT PHILLIP

Length-interval (cm.)	Lakes Entrance			Port Phillip		
	Mean L	Mean S	No. of Observations	Mean L	Mean S	No. of Observations
4.5				47.00	1.08	4
5.0				51.00	1.46	3
5.5				57.00	1.19	1
6.0						
6.5				66.00	1.69	1
7.0	73.60	1.94	5			
7.5	77.53	2.10	17	79.00	2.19	1
8.0	81.56	2.27	18	83.17	2.26	6
8.5	87.09	2.41	33	86.40	2.35	15
9.0	91.89	2.53	27	92.29	2.63	7
9.5	97.42	2.70	26	95.50	3.12	4
10.0	102.09	2.84	23	102.48	3.16	31
10.5	107.14	3.00	36	107.19	3.35	69
11.0	112.34	3.16	29	111.74	3.39	102
11.5	116.97	3.45	35	117.28	3.56	54
12.0	121.83	3.52	29	121.86	3.84	77
12.5	126.06	3.73	16	127.25	4.00	81
13.0				131.24	4.20	184
13.5				136.56	4.30	218
14.0				141.60	4.50	78
14.5	145.00	4.83	1	146.61	4.57	36
15.0	152.00	4.22	1	151.29	4.79	14
15.5	157.50	4.64	2	156.50	4.92	2
16.0						
16.5						
17.0	170.00	5.15	1			
17.5						
18.0	183.00	5.72	1			
Total			300			988

1949, p. 28) that where the L/S relationship is of this type the corrected intermediate lengths are obtained from the formula

$$L_n = L_{n^1} + A\ \left(1 - \frac{L_{n^1}}{L}\right)$$

where A is the intercept constant, L the fish-length, L_{n^1} the intermediate length calculated by direct proportions, and the L_n the corrected intermediate length. No inaccuracies result from ignoring the difference between the values of A in the equations for the separate localities. For example, the correction to the nearest mm. is 11 where $L_{n^1} = 60$ and $L = 180$, whether A is taken as 16 or 17.

The methods and difficulties of reading Australian pilchard scales have been fully discussed elsewhere (Blackburn 1949, Section III 2). It was also shown in Section III 3 of the previous work that a certain succession of rings of two different kinds is rather characteristic of the scale. A somewhat similar ring succession is more or less characteristic of Victorian pilchard scales. It is fully represented by: (*a*) a succession of rings of the ordinary or "yearly" type described in the previous study; (*b*) a succession of "spawning" rings as previously described, of which he first follows the second or third (rarely the first) yearly ring and the est alternate with the subsequent yearly rings; and (*c*) one or more 'secondary" or "accessory" rings associated with the first yearly ring usually preceding it) and sometimes with other yearly rings (Plate , Fig. 1; Plate 4, Figs. 1, 2). On New South Wales scales the spawning ing often completely obliterates the yearly ring immediately preceding, lthough sometimes the apical part is conserved ("casquette", see Blackurn 1949, p. 25). This obliteration may occur on Victorian scales, but ften the yearly ring remains complete inside the spawning ring, which is arely so in New South Wales material. This is explained in the following ection.

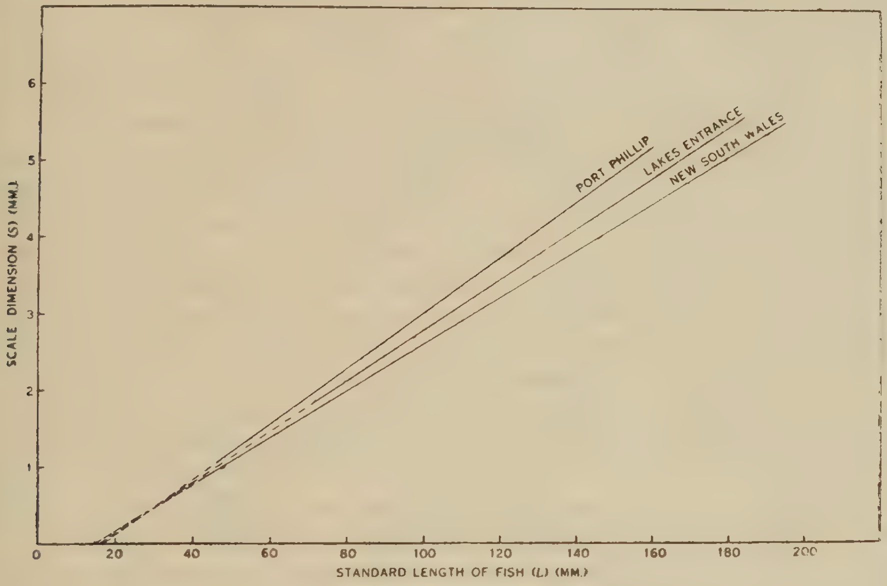

Fig. 3.—Comparison of fish-length/scale-length relationship in pilchards from Port Phillip Bay, Lakes Entrance, and New South Wales. The full lines are calculated regression lines and the broken lines are extrapolations. For further explanation see text.

Departures from this pattern, owing to faintness, incompleteness, or irtual omission of yearly rings, spawning rings which closely resemble early rings (see Section II (*d*) (iv)), unusual development of secondary rings, etc., are frequent and often puzzling, especially in scales from young fish. The older the scales, the more obvious are the departures from the complete pattern, and the simpler are the age determinations.

(ii) *Season of Ring Formation.*—The season of formation of the first yearly ring on New South Wales pilchard scales is the late spring, while all other rings are formed between late autumn and spring (Blackburn 1949, pp. 36-8). Table 3 shows, for material of Lakes Entrance and Port Phillip separately: (*a*) the numbers of definite I-group pilchard scales read and the numbers and percentages of those in which the L_1 value was determinable and was not more than 10 mm. less than L, for each month (irrespective of year) for which data were available; (*b*) similar information for II-group scales, the limiting value of L_2 being 5 mm. below L; and (*c*) similar information for III-group and older scales combined, the limiting value of L_3, L_4, etc., being again 5 mm. below L. As spawning rings may simulate yearly rings, and as both are not always represented in a year's scale growth, the L_n values represent a mixture of both kinds of rings. Where a second-year pair occurred the L_2 value of the inner ring was selected; where a pair occurred in the growth of a later year, the L_n value of the outer ring was taken. The first year's growth was usually complicated by secondary rings, and so such pairs were not detectable (see Section II(*d*) (iv)). It is shown in the following section that there were many scales which could not definitely be allocated to age-groups, and these are consequently neglected in Table 3. But as the presence of a ring near the edge was one of the criteria for age determination, it follows that the percentages in Table 3 are rather high and, for this and other reasons, the differences in percentages between months are not significant. Actually, Table 3 shows merely that ring formation occurs on a significant scale at a certain season.

It is clear that all the rings are formed at much the same season, which is fortunate in view of the difficulty of distinguishing the two kinds.* This season is identical with the season of growth of the fish (Section II(*b*)). For the New South Wales pilchard, this applies only to the first yearly ring, the others being formed at the season of least growth, which is the situation generally encountered in other fish. It is for this reason that the yearly and spawning rings of the same year are, when both present, usually well separated on the Victorian pilchard scales. In the New South Wales material they are both formed at the season of least growth, so that the later ring partly obliterates the earlier.

In both the New South Wales and Victorian pilchard the season of ring formation at any age is always that at which the fish school in greatest abundance in the surface waters. This season is the spring for one-year and winter for older fish respectively in New South Wales, and the spring and summer for fish of all ages in Victoria.

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* The rings considered were predominantly of the yearly type for I- and II-group scales, and predominantly of the spawning type for older material. (See explanation of Table 3 in text.) A small proportion of scales of Westernport fish taken in July and August also bore one yearly ring.

TABLE 3

NUMBERS OF SCALES OF THE STATED AGES, AND NUMBERS AND PERCENTAGES WITH INTERMEDIATE LENGTHS WITHIN CERTAIN LIMITS OF FISH-LENGTH. LIMITS ARE 10 MM. FOR THE I-GROUP, OTHERWISE 5 MM.

Lakes Entrance

Month	I-Group			II-Group			Older Groups		
	Total No.	No. with Ring in Limits	%	Total No.	No. with Ring in Limits	%	Total No.	No. with Ring in Limits	%
Aug.				2					
Sept.	37	16	43	52	29	56	14	8	57
Oct.				22	21	95	7	7	100
Nov.									
Dec.	26	8	31	6	2	33			
Jan.				5					

Port Phillip

Month	I-Group			II-Group			Older Groups		
	Total No.	No. with Ring in Limits	%	Total No.	No. with Ring in Limits	%	Total No.	No. with Ring in Limits	%
Aug.									
Sept.							8	6	75
Oct.							112	103	92
Nov.	1						143	131	92
Dec.	25	7	28				12	9	75
Jan.				71	27	38	82	71	87
Feb.				49	27	55	101	80	79
Mar.				19	2	11	73	65	89
Apr.							21	18	86
May				2	1	50	49	43	88

(iii) *Age and Growth Rate.*—The identity of the growing and ring-forming seasons raised additional and unusual problems in a study which would have been difficult in any event. The study of the New South Wales material emphasized the intricacy of the task of identifying all the rings on pilchard scales, and some of the methods which proved helpful (Blackburn 1949, pp. 31-6) were inapplicable in the Victorian work. For deciphering bad New South Wales scales it was often very useful to refer to modal values of L_1, L_2, etc., established from indubitable examples from fish of similar size. These modes were distinct because the rings to which they referred were mostly formed at the season of minimum growth of fish and scale, but this did not apply to the Victorian material.

However, the main difficulty was not so much the identification of all the rings, but determining the age even when all the rings were counted. In very many instances it was impossible to make certain that another ring would not have formed within a short time if the fish had lived, because most of the material was obtained in the season of fish growth and ring formation. In other words, the age could have been a year more than that indicated by the number of rings present. Since the yearly ring-forming process ends with the formation of the spawning ring, it was safe to conclude that no more rings were due to appear if the gonads were spent, and this was also assumed if the fish was captured very late in the season, e.g. April and May at Port Phillip. For the rest, all rings represented by L_n values no more than 5 mm. below the fish-length were considered to represent rings-of-the-year, but there were many scales whose age could not be determined by any of these methods.

It is convenient to state briefly the situation that was encountered with the scales of fish of successive half-cm. length groups, as was done in the New South Wales study (Blackburn 1949, pp. 38-42).

The smallest fish encountered were at 4.5, 5.0, and 5.5 cm., in February and March (Port Phillip) and July to September (Westernport). Some had postlarval characters and the scales mostly bore no rings, although a few had rings which it was impossible to regard as anything but secondary. These fish were obviously hatched in the previous summer and autumn (O-group).

Fish of 6.0 and 6.5 cm. were obtained in May (Port Phillip), July to September (Westernport), and September (Lakes Entrance). A few had rings which could be accepted as yearly and not secondary, even though these occurred as early as July (at Westernport). Apparently some fish of these sizes are aged one year or almost so (I-group), while others are considerably less.

The 7.0, 7.5, and 8.0 cm. groups were represented by specimens taken from July to September (Westernport), September to December (Lakes Entrance), and November to December (Port Phillip). Many of these bore undoubted yearly rings and there are no grounds for regarding any as anything but one year old, or a few months more or less than one year.

The same observations applied to the 8.5 cm. group, but some fish of this size must be two years of age, because L_2 values down to 85 mm. were obtained from other scales. The possibility of admixture of the I- and II-groups is also indicated by length frequencies, e.g., for September fish of Lakes Entrance in Figure 2.

Fish at 9.0, 9.5, and 10.0 cm. were taken at similar seasons at the above-mentioned places, except that there were no 10.0 cm. or larger individuals in the July to September runs at Westernport. Scale readings revealed many undoubted cases of both I- and II-group individuals in the

9.0 and 9.5 groups, and many whose age was uncertain although one yearly ring was present. There were very few certain I-group individuals among the 10.0 cm. fish.

Specimens at 10.5, 11.0, and 11.5 cm. belonged to the II- or the III-group. This was also the case with fish of 12.0 cm., but some must also belong to the IV-group, since the minimum value of L_4 is 123 mm. In these and most succeeding groups there were cases in which the age could not be determined with certainty, for the reason given above.

From similar scale evidence, Victorian pilchards at 12.5 cm. may be two, three, or four years old; at 13.0 cm., three or four years; at 13.5, 14.0, and 14.5 cm., three to five years; at 15.0, 15.5, 16.0, 16.5, and 17.0 cm., four or five years, although the numbers of such fish were not large; at 17.5 cm., five or six years (only five clear instances); and at 18.0 cm., six years, from the evidence of the single fish which had clear scales, being the largest recorded Victorian specimen. Six years was also the greatest age recorded for any New South Wales pilchard (Blackburn 1949, p. 42).

The growth rate of the Victorian pilchard is much less after the first year than that of the species in New South Wales. The comparison is most conveniently made by comparing the range of L_1, L_2, etc., for the two regions (cf. Blackburn 1949, pp. 55-6). It is emphasized that the first ring represents an age of about 1¼ years in New South Wales, compared with 1 year in Victoria. A few II-group New South Wales fish as small as 9.5 cm. have been found since the 1949 paper was written, so that L_2 may occasionally be a little less than 100 mm.*

	Victoria	New South Wales
L_1:	61—104 (43)	64—111 (47)
L_2:	85—127 (42)	100—143 (43)
L_3:	107—147 (40)	129—165 (36)
L_4:	123—165 (42)	151—181 (30)
L_5:	137—177 (40)	

It would be desirable to investigate the factors responsible for this large variation in fish-length at the time each ring is formed. This might indicate the mean sizes attained at successive ages in different localities, for instance. It was pointed out in studies of New South Wales pilchard and Victorian and Tasmanian anchovy scales (Blackburn 1949, pp. 46-57; 1950, pp. 25-31, 47-8) that L_n variations could be associated with differences in sex, locality, year-class, age-group, and relative size at the same age. The last-mentioned factor was found to be important in both studies. No other factor was clearly important in the pilchard work, but the analysis was not exhaustive; in the anchovy work variation between age-groups and localities was significant, and variation between year-classes and sexes was possibly significant.

* The New South Wales scale readings of II-group and older fish summarized in the 1949 paper were mainly from waters north of Sydney. A considerable amount of material from more southern waters has since been examined, and the growth rate found to be the same.

The Victorian pilchard scale reading showed that the scales of certain fish had L_n values which were consistently high at all ages, while others had values which were consistently low. These fish were, of course, those which were respectively large and small for their age. It is sufficient to refer to the demonstration of this effect in the New South Wales pilchard study, and to the fact (shown above) that the range of values is almost the same for each ring, which means that the possible opposing (adducent) factor of growth compensation is inoperative (see also Blackburn 1950, pp. 25-7). As mentioned in the previous studies, these observations probably do not denote real differences in growth rate, but merely minor differences in age among individuals of the same age-group, occasioned by the considerable spread of the hatching season.

Owing to this variation of intermediate lengths with size of fish, and to the fact that the size of the fish of a given age may alter at the period of ring formation, it is practically impossible to pursue the analysis of dispersive factors. For example, the mean intermediate lengths of II-group fish of the 1943/44 year-class (L_1, L_2) and of I-group fish of the 1947/48 year-class (L_1) were compared for Lakes Entrance and Port Phillip material. In the first comparison the Lakes Entrance fish were the larger, and so had the higher L_n means; in the second they were smaller than those of Port Phillip, and the L_n means were correspondingly low.

It is also impossible to indicate mean sizes at successive ages, as was done for the New South Wales pilchard. Using L_n medians instead of means, the average growth rate of Victorian pilchards may be taken as approximately 8.0, 10.5, 12.5, 14.0, and 15.5 cm. of standard length at the ages of 1, 2, 3, 4, and 5 years respectively. New South Wales fish are smaller at 1 year, about the same size at 1¼, and from 1.5 to 2 cm. larger at 2, 3, and 4 years (Blackburn 1949, pp. 46-57). The standard lengths at the successive ages are very approximately equivalent to total lengths of 9.5, 12.0, 14.5, 16.5, and 18.0 cm., or about 3¾, 4¾, 5¾, 6½, and 7 in. Reference to Figure 7 in the 1949 paper, wherein all known growth rates of pilchard stocks were compared, shows that the Victorian *Sardinops neopilchardus* grows very little faster than the Mediterranean stock of *Sardina pilchardus,* which is the slowest-growing of all. The growth rate of *Sardinops neopilchardus* in New South Wales waters is comparable with that of *Sardina pilchardus* on the Atlantic coast of south-west Europe.

(iv) *Significance of the Rings.*—In the study of New South Wales pilchard scales, in which the pattern of ring succession is rather similar to that in Victorian material, an attempt was made to investigate the formation of each kind of ring. Three main hypotheses were advanced with regard to the spawning, yearly, and secondary rings respectively (Blackburn 1949, pp. 58-67, 34-5). In the light of the Victorian work, two of these hypotheses stand but one must be abandoned. The facts are relevant to the study of clupeid scales in general.

Zamakhaev (1940) recognized as spawning rings certain rings of a very distinct type which occur on some scales of Caspian shads. Similar rings were found on scales of New South Wales pilchards, where they tend to obliterate the immediately preceding yearly rings (see Section II(*d*) (i) of this paper). This also occurs on the shad scales. There were indications that these marks also denoted spawnings in the pilchard, and the present study provides fuller evidence to support this point.

Plate 1, Figure 1, Plate 4, Figures 1 and 2, and Plate 5, Figure 1 show clear spawning rings of the kind described in the Caspian shad and New South Wales pilchard studies. They show association and sometimes interaction with the later yearly rings.

These rings are not found on scales of fish which have never begun to mature, but they may occur in those with gonads at any stage of maturity from 2 to 7. This was concluded from a study of scales of females of known maturity stages, the stages in males being unreliable for this purpose (cf. Section II(*c*)). Actually, there was one female recorded as at stage 1 whose scales bore such rings, and the specimen was not available for checking. The immaturity recorded is doubtful because the fish was 133 mm. long and four years old (cf. Table 1), and the stage in question might have been 2.

It was also shown previously that the rings in question are formed at the spawning season. All these observations point to the association of the rings with sexual maturity or its onset, but a reasonable hypothesis is required to explain the manner of their formation. Zamakhaev noted that they were conspicuous only on scales from the middle of the flank, and from this and the appearance of the marks he concluded that they represented fractures of the scale margins, caused by shrinking of the skin following the loss of condition habitually associated with gonad development. The author pointed out (Blackburn 1949, pp. 58-62 and references) that this hypothesis originated with the work of Johnston (1905) on the salmon, *Salmo salar,* but was rejected by later workers on that species. The question of its validity for clupeid scales was left open.

It appears from the present study that the fracture hypothesis is satisfactory in the main for the clupeid scale, although absorption (the alternative hypothesis favoured by recent workers on salmon spawning marks) is also involved. The appearance of the rings on pilchard and shad scales very strongly suggests this. They are much sharper and more even than salmon spawning marks. Plate 1, Figure 2 shows a scale in which the spawning ring of the fourth year is in process of forming; on each side of the scale the preceding yearly ring, and almost all the other scale growth of the fourth year (i.e. practically up to the previous spawning ring) has been lost as the result of a single break or tear along the margin. The apical part of the fourth yearly ring remains, and would appear as "casquette" formation at a later stage in the growth of such a scale (cf. Plate 1, Fig. 1). However, the spawning rings are usually complete in the apical portion also, where they do not appear to represent fractures and where fractures would not be expected. This cannot be explained from Zamakhaev's original hypothesis.

Several scales were examined from each of seven parts of 20 pilchards. The seven body areas were: (1) dorsal half of the part of the flank anterior to the pectoral fin tip, (2) ventral half of the same, i.e. around and under the pectoral fin itself, (3) dorsal half of the sub-dorsal part of the flank, (4) ventral half of the same, i.e. the area from which scales were normally taken, (5) dorsal half of the part of the flank between the dorsal and anal fins, (6) ventral half of the same, and (7) posterior to the anal fin origin. Plate 2, Figure 2, and Plates 3, 4, and 5 show representative scales from these respective areas on the same fish. The area 4, 5, and 6 scales show the spawning ring of the third year and it can be distinguished on the other scales where it has, however, almost the appearance of a normal yearly ring. This bears out Zamakhaev's observations on shad scales.

Furthermore, even some scales from area 4 have spawning marks which resemble yearly rings. This is shown clearly for the spawning ring of the third year in Plate 2, Figure 1, which differs little in appearance from the preceding yearly ring with which it is paired. The same must apply very frequently to spawning marks of the second and first years, which are much rarer on area 4 scales than would be expected from the findings of Section II(*c*). Fully developed spawning rings of the second year are not uncommon but they do not occur on the majority of scales; but second-year pairs, of which the outer ring obviously represents the spawning ring in the same way as in the example mentioned above, are often encountered. Fully developed first-year spawning rings, which would be expected in Lakes Entrance material, are of very rare and doubtful occurrence. They probably occur in the guise of yearly rings, but this cannot be proved because the first-year ring succession is generally complicated by secondary rings.

All these observations can be explained by the following hypothesis, which is an elaboration of that of Zamakhaev. In some clupeids the deterioration of body condition, which accompanies seasonal gonad maturation, occasions absorption of the margins of all scales, whereby a concentric ring (resembling the ordinary ring which was formed earlier in the year) is formed. More or less simultaneously, the loss of girth in the middle trunk sections of previously fat fish causes skin shrinkage and consequent fracture of the dorsal and ventral margins of the embedded portions of scales, on those sections of the fish only. This may be facilitated by a weakening of the edges during the absorption process. This hypothesis does not necessarily apply to salmonoids. The "spawning ring" is thus really a "condition ring."

The postulated scale absorption may represent a transference of scale material to the gonads, but there are other possible explanations

(Van Someren 1937 and references). It is well known that reserves of somatic fat are expended during maturation in fishes. This definitely applies to the North American pilchard (Clark 1928, pp. 22-7) and almost certainly to the Australian species (see Section VI). Dill (1921; see also Clark 1928) showed that the percentage fat content of small North American pilchards, which can be identified from other publications as being immature and under three years old, is not nearly as high at any season as the seasonal maximum in larger fish. Small Australian pilchards, even immatures at the season of optimum plankton availability, have also a low fat content (see Table 4, especially samples 6 and 7). It is thus probable that pilchards often do not attain their maximum fat content until after first maturity, and the high rate of length increase in early life supports this view. This would explain the absence of fracture effects in spawning ring formation in one-year, many two-year, and some older Victorian fish, and the fact that they are not found quite so frequently as might be expected on scales of New South Wales fish (Blackburn 1949, Section III 3).

The formation of yearly rings on pilchard scales was previously ascribed to seasonal reduction of growth rate of fish and scale (Blackburn 1949, pp. 62-6). Although this interpretation was opposed by Graham (1929, pp. 41-3) it is widespread in scale investigation literature, largely because the season of ring formation generally coincides with that of slowest growth. The investigations of Robertson (1933) and others had made it seem particularly applicable to clupeid scales and, in spite of some apparent inconsistencies in the data, the author was not deterred from adopting the hypothesis for New South Wales pilchard material. But as all the rings on the Victorian scale are probably formed at the season of maximum growth (Section II(*d*)(ii)), the hypothesis cannot reasonably be retained for the clupeid scale. Molander (1946) has objected to it on similar grounds. It was also observed in the New South Wales work that the seasons of formation of the yearly rings, though not the same in all years of life, are consistently the seasons at which the fish form surface shoals. As mentioned in Section II(*d*)(ii), this also applies to Victorian pilchards, and shoal formation is now the only known factor which could possibly be correlated with the formation of yearly rings in this species (see also Section V(*b*)).

A third statement in the earlier pilchard study was that secondary rings tend to appear on the majority of scales from the same fish, though not on scales from the majority of fish in the population (Blackburn 1949, pp. 34-5). The observation is by no means new, but many workers still claim that secondary rings are found only on occasional scales from the same individual, in contrast to the other rings which are said to occur on all scales, in clupeids (including pilchards) and other fish. The series of scales in Plate 2, Figure 2, and Plates 3-5 show that two secondary rings, formed in the first year of life, are recognizable on scales from seven representative body areas (see above), just as are certain other rings. A third secondary ring, of the second year, is not clearly visible on all scales, but neither are the first, third, and fourth yearly rings. Actually, there are very faint traces of all these rings on most of the scales. The entire ring succession evidently tends to be repeated on the majority of scales. The distinctness of the rings varies from scale to scale, occasionally to the point of disappearance, but this is just as characteristic of yearly as of secondary rings.

(v) *Remarks on Life History.*—Since almost all the information on Victorian pilchard occurrences refers to bays and other shallow waters, an adequate statement of the life history cannot be given.

New South Wales pilchards hatch in the neritic waters in the colder months, enter bays or inlets as postlarvae, return in shoals to the sea at slightly over one year of age (in spring), and reappear there in surface shoals every spawning season, being inconspicuous between spawnings. Reappearances in bay waters, are sporadic (Blackburn 1949, pp. 74-7).

The distribution data on pilchards at Lakes Entrance could be reconciled with a similar scheme of life history, although the subject requires much further research. Reference may be made to Section II(*a*)-(*c*) of this paper. Spawning presumably occurs at sea, because no traces of eggs and larvae have been found in numerous plankton hauls in the inlet at the spawning season (spring). No such traces have been found at sea in this area either (although they have elsewhere), but very little plankton work has been done. One sample of yearling fish was taken in September several miles up the inlet from Lakes Entrance, and this could represent a seaward migration after a period of inlet residence. If such a movement takes place, the shoals that occur off Lakes Entrance in the spring and early summer might represent a mixture (*a*) of yearlings from the lakes, and (*b*) of older fish of the neritic zone making their yearly appearance as spawning shoals. Both groups appear to disperse seawards.

At Westernport, the late winter and spring shoals of yearlings at the bay entrance may also represent an emigration to the sea.

The situation at Port Phillip Bay is obscure. There is spring and summer spawning in the bay and postlarvae occur in late summer and autumn. Yearlings have been found from Port Melbourne to the entrance of the Bay. The latter occurrences, and those which have been noticed at sea (*ex* barracouta) off Lorne and Port Fairy, may represent a movement out of inshore waters. Pilchards of greater ages frequently occur inside the bay at the spawning season and have been located there below the surface between spawning seasons, and nothing is known of outside occurrences.

III. THE PILCHARD IN TASMANIA

Although an intensive search for all kinds of pelagic fish was conducted for several years on the east coast, and other areas were also explored from time to time, relatively few traces of pilchards have been found in Tasmanian waters.

Research vessels have located a few surface shoals of fish, believed to be pilchards, from March to June between Cape Pillar and Oyster Bay (Fig. 1). The identification of the shoals is not as simple in Tasmania as it is elsewhere, because the characteristic surface shoaling habit of the pilchard is simulated by another clupeid, the sprat, *Clupea bassensis*, which occurs only in Tasmania. Aerial reconnaissances revealed no pilchard shoals. Specimens of pilchards have been obtained from beach seine catches and barracouta stomachs from January to July between the D'Entrecasteaux Channel and Oyster Bay. There were previous records of this species from the east coast (Blackburn 1941, p. 21). There is no evidence that it occurs on any other part of the Tasmanian coast, and it is obviously not common anywhere. Plankton hauls were made at many east coast localities at all times of year, and in various north coast waters in spring, summer, and autumn, in different years; but the only pilchard material obtained was one larva taken in April about 40 miles off the central north coast (Blackburn 1941, p. 36).

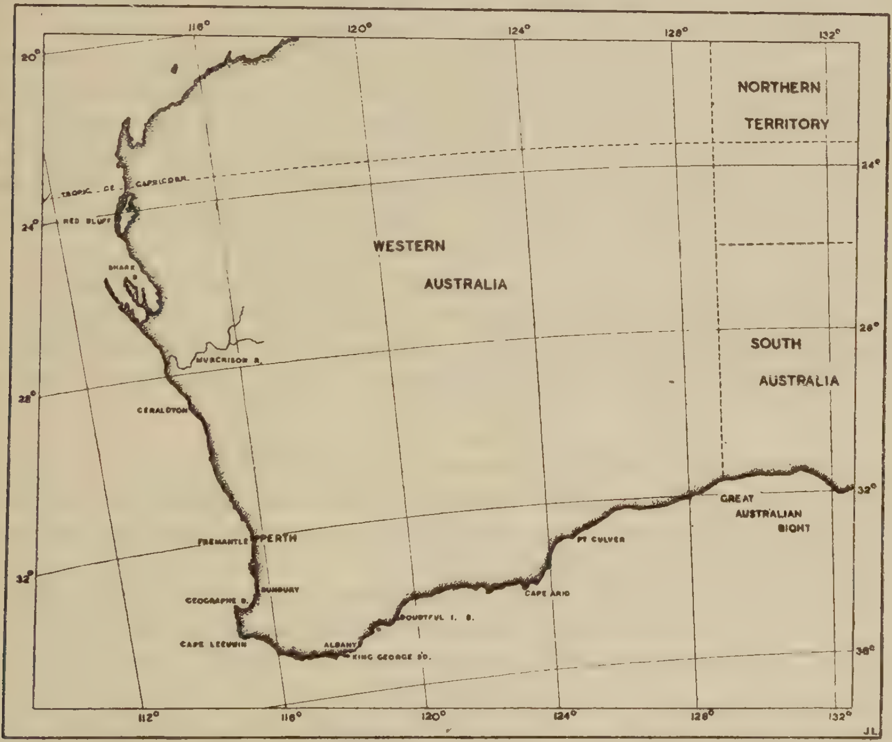
116°
120°
124°
128°
132°
20°
NORTHERN
TERRITORY
24°
TROPIC OF CAPRICORN
RED BLUFF
24°
SHARK B
WESTERN
AUSTRALIA
28°
MURCHISON R.
SOUTH
AUSTRALIA
28°
GERALDTON
32°
GREAT
AUSTRALIAN
BIGHT
FREMANTLE
PERTH
PT CULVER
32°
BUNBURY
GEOGRAPHE B.
CAPE ARID
DOUBTFUL I. B.
CAPE LEEUWIN
ALBANY
KING GEORGE SD.
36°
112°
116°
120°
124°
128°
132°
JL

Fig. 4.—Western Australia, showing localities mentioned in text.

Of the 380 specimens measured (see Appendix II for details of samples), 369 were taken in Fortescue Bay (near Cape Pillar) from January to May 1941. These included the smallest and largest Tasmanian specimens, which measured respectively 114 and 197 mm. The latter measurement represents 231 mm. or 9.0 in. total length, and this was the largest Australian pilchard seen by the author. The next largest specimen, from New South Wales, measured 196 mm. in standard length. The other 367 Fortescue Bay pilchards appeared to belong to one normal frequency distribution of which the limits were 148 and 190 mm., and the mode 168 mm. The Tasmanian pilchard scales available for study were all from this Fortescue Bay material. There were only 72 scales available from fish of known sizes, and many were in bad condition. Most of them, including some from fish of 150 to 182 mm., exhibited a ring pattern very similar to those of five-year Victorian pilchards taken in spring, summer, or autumn, having either the yearly or the spawning ring of the fifth year at or just inside the scale margin. Some individuals, including one 148 mm. long, were possibly only four years old. These scanty observations conform with the growth rate established for the Victorian pilchard rather than with that in New South Wales (cf. Section II(*d*)(iii)).

The only January specimen was at maturity stage 5. Most of the specimens were taken in April and May, when all were at stage 7. A single June fish had gonads at stage 2. This suggests that the reproductive season is similar to that of the pilchard in Victorian waters (cf. Section II(*c*)).

IV. THE PILCHARD IN SOUTH AUSTRALIA

The species is common in this area, but the available information, even regarding distribution, is scanty. There is no fishery, and research vessel surveys have been infrequent.

The vessel surveys took place in December, February, March, April, and May of various years. No surface shoals were seen in December, but pilchards were found in stomachs of southern bluefin tuna (*Thunnus maccoyii*) taken in St. Vincent's Gulf and Backstairs Passage (Fig. 1). In February and March, some pilchard shoals were found near Cape Borda and Port Lincoln, and the fish were plentiful in stomachs of tuna and barracouta taken in many places between Lacepede Bay and Cape Catastrophe. The surveys in these earlier months covered the area from the Victorian border west to Cape Catastrophe, while those in April and May extended from the Western Australian border to St. Vincent's Gulf. On the latter surveys the shoals were found to be much more numerous and widely distributed, the main areas of occurrence being the north coast of Kangaroo Island, the entrance to Spencer Gulf, and near the Investigator Group. Specimens were found in tuna and barracouta stomachs in these and other localities. All the shoals were identified by observers with previous experience of pilchards, and in many instances specimens were available (see Section V(*a*)).

Aerial reconnaissances were made from February to April in various years, and once in October and November. In the former period, pilchard shoals were found, often abundantly, off Lacepede Bay, the south coast of Kangaroo Island, the entrance to Spencer Gulf, and from Point Westall to the Investigator Group. In the latter period none was seen. The aerial observer had had previous experience of pilchard shoals in other Australian waters.

Other observers have noted pilchards in some of the same areas between February and May. In inshore waters there have been captures by beach seine from April to early July in the Port River at Adelaide; by beach seine in May at Port Lincoln; and by beach seine and lampara from November to May inside the bar at Coffin Bay.

Eggs and larvae were taken in plankton nets at one of the three neritic zone stations worked in December, and at four of the six worked in February and early March (Blackburn 1941, pp. 128, 133). They were absent from hauls made at one station in April and at eleven stations in May. Fish with gonads at stage 5 have not been collected. Stage 7 has been seen in May, but not as commonly as the recovering stage 2.

Although the data are limited and do not cover all seasons, it is reasonable to conclude that the seasons of reproduction and surface availability approximately coincide, as they do in Victorian and New South Wales waters. The season in question comprises summer and autumn, and its peak is probably later than at Port Phillip Bay.

Specimens available for measurement totalled only 1,695 (see Appendix III), and 1,622 of these were taken in Coffin Bay from March to May, in different years. Two distinct size-groups were represented in the Coffin Bay material, with modes at about 7.5 and 10.0 cm. respectively. This is like the length frequency distribution of Lakes Entrance pilchards in September, i.e. at the spawning season in that area (Fig. 2).

Scales numbering 428, from 133 fish, were read. The material was inadequate for determining the *L/S* relationship and hence the intermediate lengths. It was all taken from December to May, and the outermost ring on most scales was not far from the edge, in some instances very close to it. Thus, where the number of undoubted yearly rings was plain it could often be taken to indicate the age, although some cases were doubtful because the ring was well inside the margin. The results in terms of age for size (numbers of fish in brackets) are as follows:

7.0 and 7.5 cm. (29) — Probably all I-group
8.0 and 8.5 cm. (18) — Mostly I- and a few possibly II-group
9.0 to 10.0 cm. (17) — I- and II-group
10.5 to 12.5 cm. (61) — II- and III-group
13.0 cm. (3) — III- and IV-group
13.5 cm. (3) — III-group
15.0 cm. (1) — IV-group
16.0 cm. (1) — Doubtful

From these observations, the growth rate of South Australian pilchards could be exactly the same as that of Victorian fish, and is certainly less than that established for New South Wales (cf. Section II(*d*)(iii)). The few specimens taken in the gulf or open sea waters ranged from 71 to 174 mm., but larger fish have been reported.

V. THE PILCHARD IN WESTERN AUSTRALIA

(*a*) *Distribution*

Before 1941, all that was known about the pilchard in Western Australia was the bare fact that it occurred there (Blackburn 1941, pp. 17-8). From 1941, specimens gradually came to hand from fishermen and fisheries inspectors. Aerial reconnaissances from 1943 to 1946 and research vessel surveys from 1945 onwards have shown the species to be common over a very large area. Commercial fishing operations began at Albany in 1949.

The northernmost record of the pilchard is off Red Bluff, just south of the Tropic of Capricorn (Fig. 4). This is in practically the same latitude as the known northern limit of distribution in eastern Australia (Blackburn 1941, p. 34). For convenience in summarizing the information on seasonal distribution, the coast south of Red Bluff is divided into six sub-equal areas. The monthly records are given without regard to year.

Area 1.—South Australian border to (but not including) Point Culver; traversed by research vessel in March and May. A few pilchard shoals were seen in May, and a pilchard larva was obtained by plankton net, in both instances near the border. No plankton work was done in March.

Area 2.—Point Culver to (but not including) Doubtful Island Bay; traversed by research vessel in all months from March to July. Pilchard shoals were numerous in May, fewer in June and July, and there was concurrent evidence of pilchards from mesh nets and barracouta stomachs, and general occurrence of eggs and larvae (up to 400 eggs for a 15-minute surface haul with the N70 plankton net). No plankton work was done earlier in the year than May. Aerial reconnaissances in May and June revealed the presence of abundant shoals over most of the area, especially east of Cape Arid. In this locality, 10,000 shoals (minimum estimate) were seen on a single day. This was the greatest concentration of any fish seen from the air in Australian waters. Pilchards occur plentifully in the stomachs of Australian salmon (*Arripis trutta*) between November and June.

Area 3.—Doubtful Island Bay to Cape Leeuwin; traversed in all months from January to July. Shoals were numerous in May and June and none was seen in July, but pilchards were found in all three months in stomachs of southern bluefin tuna, oriental bonito (*Sarda orientalis*), barracouta, or other fish. Eggs (up to 2,000 for a 15-minute surface N70 tow) and larvae occurred fairly consistently in the plankton in these three months, which were the only ones in which plankton work was done.

Pilchard shoals were found commonly in King George Sound, near Albany, from May 9 to June 4, 1948, when 28 experimental lampara net hauls took 4¼ tons. In 1949 a canning company caught 16½ tons with lampara and small purse-seine nets from May 14 to June 15. This appears to be the best season for surface shoals at this locality, but reports from fishermen and fisheries inspectors indicate that shoals may occur from February to October, though rather sporadically after June. Except for one in January, all other reports of pilchards refer to that period.

Area 4.—Cape Leeuwin to (but not including) Fremantle; traversed in all months from November to July. Shoals were moderately abundant from November to February and April to May, but very little time was spent in the area in other months. Pilchards were taken in mesh nets in November, January, and April, and found in stomachs of southern bluefin, oriental bonito, or other species in the various months from November to July. Plankton catches were taken only in November, December, April, and May, and some in each month contained pilchard eggs (up to 360 for a 15-minute N70 tow, in November).

Most of these pilchard occurrences were in the Geographe Bay-Bunbury sector, where local fishermen and inspectors regard the summer and autumn as the season of greatest abundance. This is open to question, although it agrees with the results of research vessel surveys. The winter weather in this area is inclement by comparison with areas 2 and 3, where there is more shelter from westerly winds. Therefore the fishermen do little winter work off-shore, and the research vessel has so far found more profitable employment in other areas at that season. Pilchards could thus occur abundantly without often being observed, and it appears significant that shoals have been seen from aircraft in May and July.

Area 5.—Fremantle to Murchison River. The area immediately off Fremantle has been surveyed by research vessel in every month of the year except October, and pilchard shoals were observed in March, May, and July, being especially numerous in July. Plankton was obtained in April, June, July, August, November, and December, and some of the April, November, and December catches contained pilchard stages. Specimens of adult pilchards have been procured in May and July. The area as a whole has been traversed in July, August, September, November, and December. Plankton catches were made in all these months, some of those of August (up to 150 eggs for a 15-minute surface N70 haul) and December containing pilchard material. A few shoals were seen in August and pilchards were found in mackerel tuna (*Euthynnus alletteratus*) in September. This area has received less attention in research vessel surveys than any other except Area 1. Geraldton fishermen have stated that the optimum pilchard season is May to July.

Area 6.—Murchison River to Red Bluff; traversed in all months from July to December. Pilchard shoals were seen in Shark Bay in September. Specimens were found in stomachs of yellowfin tuna (*Neothunnus* *macropterus*), northern bluefin tuna (*Kishinoella tonggol*), large-scaled tunny (*Grammatorycnus bicarinatus*), and inky-tail shark (*Longmania calamaria*—see Whitley 1945, p. 6) in August and September. Plankton work was done in September, October, and November, but no pilchard material was obtained. Aerial reconnaissances revealed the presence of pilchard shoals in Shark Bay in all months from August to November, the number seen on one occasion in October being estimated at a thousand. Shoals have been reported by a fisherman in April.

The observers on boats and aircraft who identified the pilchard shoals had mostly had previous experience of this species. The question of the reliability of such identifications was discussed in earlier papers (Blackburn 1941, pp. 26-7; Blackburn and Tubb 1950, pp. 20, 29), where it was shown that pilchard shoals have certain characteristic features. There is a possibility that shoals of mackerel (*Pneumatophorus australasicus*) were occasionally identified as pilchard in Western Australia, but the two species seem often to shoal together, as they also do in New South Wales. Many of the above-mentioned occurrences of shoals were positively identified from specimens, and it may confidently be said that the identifications are in the main correct.

In the Albany, Fremantle, Geraldton, and Shark Bay areas, plankton stations have been worked up to 100 miles offshore, although most of the catches were taken within 10 miles off. Pilchard stages have been obtained up to 40 miles from the coast, i.e. near or just beyond the edge of the continental shelf. Their distribution is thus practically confined to the neritic zone, as it is in eastern Australia (Blackburn 1941, p. 34). Eggs have been found inside King George Sound, but in diminishing numbers towards the head of the Sound.

The information on seasonal distribution is incomplete, since all-season observations have not been made in any area except the offing of Fremantle. However, pilchards are obviously not uniformly abundant in surface waters all the year round (see Area 3 and Fremantle), and the season of greatest abundance is not the same in all areas (cf. Areas 3 and 6). In eastern and south-eastern Australia, this optimum season is progressively later towards the north and west respectively (see references and discussion in Sections II(*a*) and IV), and it is interesting to consider the possibility of a similar coastwise shift along part or whole of the coast of Western Australia. A southerly shift of the season, from the spring in Area 6 to summer in Area 4 and autumn in Areas 2 and 3, is at first sight a possibility, but the evidence of an autumn or winter optimum at Fremantle is against it, as are some observations from other areas. The hypothesis of a northerly shift, from the late autumn in Areas 2 and 3 to early spring in Area 6, accords better with all the evidence, bearing in mind the previous remarks on Area 4, but the position might be more complex than this. The known distribution of planktonic stages corresponds generally with that of the adult fish at their seasons of availability in surface waters, and from this and data in the next section, and from the experience in other Australian waters, it may be concluded that these optimum seasons are the spawning seasons.

(*b*) *Size, Maturity, and Age*

The total of measured fish is 4,109, of which 3,139 were taken in 12 samples between May 19 and June 3, 1948, in King George Sound, by lampara net. Only two samples from other places consisted of more than 100 fish, and most samples were very small (details in Appendix IV).

The 3,139 King George Sound specimens ranged from 115 to 185 mm. Two distinct size-groups were represented, with modes at 13.0 and 15.0 cm., but the former included only about 12 per cent. of the total number of fish. Of the 970 other fish (including 670 and 225 from Areas 2 and 4 respectively), 12 ranged from 67 to 106 mm. and 30 from 120 to 139 mm., the rest being larger. The largest specimen, which was from Area 3, measured 191 mm., i.e. very little smaller than the largest seen in the Tasmanian and New South Wales investigations. The average size of sampled Western Australian pilchards far exceeds that of any other Australian region except Tasmania.

The following is a summary of records of maturity stage 5 and stage 7 pilchards, in the areas defined in the previous section:

Area 2.—Recorded in February, May, and July; no specimens were obtained in other months.

Area 3.—Recorded in May and June, but not in April or August.

Area 4.—Recorded in November, December, March, April, and June; except for a few under 90 mm., no specimens were available for other months.

Area 5.—Recorded in July, the only specimen for any other month being under 90 mm.

These seasons are virtually the same as those at which eggs and larvae have been taken in the plankton, as shown in the preceding section. Most of the pilchards taken in these months were at the stated maturity stages, although the samples available for such examination, except from Areas 2 and 3, were relatively small. The records for these two areas indicate the time of year when spawning occurs, which is approximately the season of greatest abundance of pilchards in the surface waters, for Area 3 at least. All females over 131 mm. were at maturity stages 2-7. Few smaller ones were available for gonad examination.

Scales (950) from 322 fish were read. The material was inadequate for determining the *L/S* relationship, particularly as most of it was obtained from large fish. However, from experience of pilchard scale reading with other material, it was generally possible to assign an age to each fish. Nearly all the scales were collected in autumn and winter, and most of them showed a ring (yearly or spawning) at or near the margin. The season at which the later rings are formed is thus again the season at which the fish appear in surface shoals for spawning. On the assumption that Western Australian pilchards grow most slowly in the winter months, as they do in New South Wales and probably in Victoria (Section II(*b*)), a ring near the edge of a scale could be regarded as a ring-of-the-year, and where there was no ring near the edge it could be taken that one would have appeared within a short time if the fish had lived. Thus these scales were read like those of New South Wales fish obtained at the same season. The ring pattern also resembled that of New South Wales rather than that of Victorian scales (Sections II(*d*) (i) and (ii)).

The results of the scale readings, in terms of age for size, are summarized as follows (numbers of fish in brackets):

8.0 cm. (1) — I-group
10.5 cm. (1) — II-group
12.0 cm. (4) — II- and possibly III-group
12.5 cm. (3) — II- and possibly III-group
13.0 cm. (7) — II-, III-, and possibly IV-group
13.5 cm. (10) — III- and IV-group
14.0 cm. (27) — III- and IV-group
14.5 cm. (53) — III-, IV-, and possibly V-group
15.0 cm. (76) — III-, IV-, and V-group
15.5 cm. (69) — III-, IV-, and V-group
16.0 cm. (38) — III-, IV-, and V-group
16.5 cm. (26) — IV- and V-group, and possibly III- and VI-groups
17.0 cm. (5) — IV- and V-group
17.5 cm. (1) — IV-group
19.0 cm. (1) — Doubtful

By comparison with the findings in Section II(*d*) (iii) for Victorian fish, and with those elsewhere published (Blackburn 1949, pp. 38-42) for New South Wales, these results indicate a growth rate probably intermediate between those two. There are III-group fish as large as 15.0 to 16.0 cm., which is not so in Victoria,* and there are IV-group fish as small as 13.5 to 14.5 cm., which are not found in New South Wales. The smallest V-group fish are at least 1 cm. larger than the smallest found in Victoria, and at least 1.5 cm. smaller than the smallest found in New South Wales. These statements refer to Areas 2 and 3, which yielded 278 of the 322 fish whose scales were read, and may not apply to other areas.

* It was shown in Section II (*d*) (iii) that the numbers of Victorian fish at these sizes were not large, but reference to the ranges of Victorian L_n values supports the statement made here. For instance, one Albany pilchard 157 mm. long had an undoubted third ring at the edge, making $L_3 = 157$. If Victorian L_3 values were as high they would range over 50 mm., compared with ranges not exceeding 43 mm. for L_1, L_2, L_4, etc.

The comparison with the scanty South Australian age determinations is inconclusive. The South Australian results could conform with the growth rate in Victoria, as pointed out in Section IV, but also with that now indicated for southern Western Australia.

It is impossible to outline the life history of the pilchard in Western Australia, from the data available. There is a possibility that it is not the same as that in New South Wales. In that area the II-group predominates in the seasonal surface shoals at sea (Blackburn 1949, p. 76), but in Western Australia it appears to be unimportant by comparison with the total of older fish. This may be due to selective sampling, natural fluctuation in year-class survival, or a difference in habitat segregation of age-groups.

VI. Commercial Possibilities

This matter was discussed in previous papers (Blackburn 1941, Section IX; Blackburn and Tubb 1950, pp. 64-7), which dealt mainly with New South Wales. The following statement summarizes the relevant information for all Australian waters.

The pilchard is seasonally an abundant species in the coastal waters of the Australian mainland south of the Tropic of Capricorn. At the optimum season, pilchard shoals are usually common in the surface waters, but this season is not the same in all areas. It extends from autumn to spring in New South Wales and Queensland (being later towards the north), from spring to autumn in Victoria (later towards the west), summer to autumn in South Australia, and autumn to winter in southern Western Australia. The season on the west coast of the continent is not known with certainty. These shoals occur in the open waters of the continental shelf and in the larger bays. Pilchards may be found at other seasons, but not as commonly at the surface. The spring movement of small fish from the bays to the sea in New South Wales is such an occurrence.

In the above-mentioned papers the opinion was expressed that relatively small and shallow nets of the lampara or purse-seine type would eventually prove successful for pilchard fishing in certain bay waters. This has now been demonstrated at Port Phillip Bay (with purse-lampara fishing at night) and King George's Sound (lampara and small purse-seine used by day), and lack of demand for the fish is now the only factor retarding the development of the pilchard fishery. Suitable weather conditions are required for effective fishing by these methods, and the greatest development of pilchard fishing in Australian waters will probably be in those areas where the season of maximum surface availability of fish most nearly coincides with the calmest season of the year. Along the coasts of the southern half of Australia this season is the autumn, as shown by climatological data in Commonwealth Year Books. The mean wind speed is lower in May than in any other month in Perth, Adelaide, Melbourne, and Sydney, and March, April, and June are also relatively calm months in those areas.

It follows that pilchard fishing by the suggested methods should prove, in the end, most successful in the areas where the shoals appear in autumn or early winter. These areas include the southern half of the New South Wales coast, South Australia, and the south coast of Western Australia. In Victoria, the optimum surface availability is in spring and summer, a windy period, but there seem to be possibilities of attracting the fish to the surface in the off-season in shallow bays, by using lights on dark nights (Section II(*a*)).

Considerations of utility could also have an important influence on the kind, location, and season of any fishery that might appear. If pilchards were required for live-bait for tuna fishing, their availability at the tuna season would probably be far more significant than their availability at the calmest season. Certain seasonal occurrences of tuna coincide with those of pilchards in nearby waters, as shown elsewhere (Blackburn and Tubb 1950, pp. 64-7).

In particular, Victorian pilchards could serve as a valuable source of bait for the tuna runs of spring, summer, and autumn in the waters between Sydney and Hobart. In South Australia the tuna and pilchard seasons coincide.

Other factors which enter into a consideration of utility are size and condition. Size is generally important to canners of pilchards, sardines, or similar fish. Some packers have markets for small fish, e.g. the sprats (sild or brisling) of Norway, and others for large fish, e.g. the pilchards of Pacific North America, and all prefer a reasonable uniformity in the size of the fish caught. A considerable amount of information on the size of Australian pilchards has been given in this paper and elsewhere (Blackburn 1949). There is considerable variation within and between areas. However, from present indications, canners intending to pack large pilchards ought to seek supplies in Western Australia, while those requiring small ones would obtain them most easily in Victoria, South Australia, or New South Wales.

Condition and fatness are important factors influencing the palatability of fish for canning, and their suitability for oil production. It has been shown in this and earlier papers that the surface pilchard shoals occurring at the above-mentioned optimum seasons are for the most part composed of mature or spent fish, in all areas. Their condition may be expected to be poor. This is fully borne out by the oil content determinations summarized in Table 4.

The oil contents of sixteen of these samples range from 0.3 to 5.1 per cent. by weight of the wet fish, with corresponding oil yields from 0.8 to 12.4 imperial gallons per ton of 2,240 ib. Four of these samples, Nos. 6, 7, 12, and 14, consisted of immature fish, Nos. 6 and 7 being yearlings of the New South Wales spring run. The other twelve con-

TABLE 4

DETAILS OF AUSTRALIAN PILCHARD ANALYSES, SHOWING OIL CONTENT AND ESTIMATED OIL YIELDS OF WET FISH, GALLONS CONVERTED AT 9.2 LB.

Sample No.	Region	Date	Approximate Biological Specification			Water (%)	Oil (%)	Estimated Oil Yield (imp. gals. per long ton)
			Length (cm.)	Age	Maturity			
1	New South Wales	9.viii.39	15.0-17.0	III-IV	Spent	80.9	0.3	0.8
2	New South Wales	22.i.40	11.5-16.0	II-IV	Early maturing	67.0	14.0	34.1
3	New South Wales	23.iv.40	12.0-14.0	II-III	Early maturing	72.0	5.1	12.4
4	New South Wales	31.vii.40	11.5-13.0	II-III	Spent	78.0	1.2	2.9
5	New South Wales	6.x.40	15.0-18.0	III-IV	Maturing to spent	73.1	4.8	11.7
6	New South Wales	25.x.40	7.0- 9.0	I	Immature	75.6	2.8	7.3
7	New South Wales	8.xii.40	8.5-10.0	I	Immature	77.4	1.4	3.4
8	Victoria	23.ix.37	14.0-15.5	III-V	Maturing	75.9	1.2	3.0
9	Victoria	27.ix.37	14.0-15.5	III-V	Maturing	78.9	1.1	2.6
10	Victoria	27.i.38	14.0-15.5	III-V	Maturing to spent	76.5	1.1	2.7
11	Tasmania	19.iv.41	17.0-17.5	V	Spent	81.4	1.7	5.2
12	S. Australia	28.iii.40	9.0-10.5	I-II	Immature	72.8	4.5	10.9
13	W. Australia	15.vi.46	14.5-16.5	III-V	Spent	75.5	1.0	2.4
14	W. Australia	—.v.48	11.5-13.5	II-III	Immature	72.9	4.1	10.0
15	W. Australia	—.v.48	14.0-17.0	III-V	Maturing to spent	73.8	3.2	7.8
16	W. Australia	—.v.49	14.0-17.0	III-V	Maturing to spent	72.5	3.3	8.0
17	W. Australia	—.vi.49	14.0-17.0	III-V	Maturing to spent	73.8	1.5	3.6

sisted of maturing, ripe, or spent pilchards taken in or near the shoaling season. The remaining sample, No. 2, with a very much higher oil content, was the only one consisting of adult fish taken midway between spawning seasons.

These observations support those of Dill (1921) and Clark (1928, pp. 22-7) on the North American pilchard. In that species the oil content depends both on size and sexual condition: small immature fish and large fish approaching maturity have little oil compared with large fish between spawning seasons (see Section II(*d*)(iv)). It follows that none of the conspicuous seasonal runs of shoaling Australian pilchards can be expected to yield fish in prime condition. Such fish are available in the off-seasons, sometimes in night or day surface shoals (Blackburn and Tubb 1950, pp. 18-20), but probably for the most part in deeper waters, and in any event much harder to locate and capture than in the main shoaling seasons. It might be possible to obtain them in some localities, e.g. by attracting them to the surface with lights. The seasons would be the summer in New South Wales and Western Australia, and possibly winter in Victoria and South Australia. Unless such fat fish can be landed regularly in large quantities, the outlook for profitable oil reduction must remain unpromising.

VII. CONCLUSIONS

(1) In Victorian waters, surface shoals of pilchards occur most abundantly in spring and summer; the shoaling season, which is also the spawning and the growing season, is later towards the west. The fish occur and spawn in Port Phillip Bay as well as at sea.

(2) Victorian pilchards are approximately 8.0, 10.5, 12.5, 14.0, and 15.5 cm. of average standard length, or about 3¾, 4¾, 5¾, 6½, and 7 in. total length, at 1, 2, 3, 4, and 5 years of age. Few 6-year and no older fish have been found. At Lakes Entrance many yearlings are sexually mature, but at Port Phillip few mature until their second year. The rest of the life history is not definitely known.

(3) Pilchards are not common in Tasmanian waters, but sometimes occur on the east coast from late summer to early winter. The spawning season is probably in the warmer months, and the growth rate is probably similar to that in Victoria.

(4) In South Australian waters, the pilchard is common in surface shoals in summer and autumn, when spawning also takes place.

(5) In Western Australia the species ranges almost as far north as the Tropic of Capricorn. On the south coast the main season of surface shoaling, which is also the spawning period, is in autumn and winter. The seasonal distribution on the west coast is not known with certainty.

(6) The growth rate of the species in southern Western Australia is probably higher than that in Victoria, but lower than that in New South Wales. The growth rate in South Australia is imperfectly known, and

cannot so far be distinguished from that in either of the adjacent regions. Fish over 14.0 cm. (6½ in. total length) are much more frequently encountered in Western Australia than in other Australian waters. The life cycle in that area is unknown.

(7) As in eastern Australia, pilchard shoals generally occur within a few miles of the land. Nowhere in Australian waters has any trace of pilchards been found beyond 40 miles offshore.

(8) The areas in which surface shoals occur abundantly in autumn should prove particularly suitable for lampara, purse-seine, or other pelagic net fishing. These comprise South Australia and southern Western Australia, as well as the southern half of the New South Wales coast.

(9) In southern and western Australia, as in New South Wales, the fish in the seasonal surface shoals, being small or sexually mature or both, are not in prime condition. The oil content ranges from about 1 to 5 per cent. by weight in the wet fish.

The following conclusions, from scale-reading studies, are of more academic interest:

(10) The fish-length/scale-length relationship in Victorian pilchards is linear, with two constants in the regression equation. In New South Wales and Victorian waters the mid-flank scales of pilchards tend to increase in size towards the south.

(11) The scales of southern and Western Australian pilchards bear yearly, spawning, and secondary rings in a rather characteristic succession, much as they do in eastern Australia. One yearly and one spawning ring are usually formed in each year in which the fish matures. The spawning rings are probably formed as a result of absorption, and in some cases fracture, of the scale margins, both effects being associated with loss of somatic condition during gonad maturation. The entire ring succession, including secondary rings, tends to be shown on all scales of the same fish.

(12) In Victorian pilchards the season of ring formation coincides with the growing season. This is unusual, and makes many age determinations uncertain. It also necessitates the rejection of some hypotheses on the origin of yearly rings in clupeid scales.

(13) The season of ring formation in Australian pilchards is invariably the season of availability in surface shoals. Except for certain occurrences of immature fish, this season is also always the spawning season. It is the winter in eastern and south-western Australia, and the summer in south-eastern waters.

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APPENDIX I

DETAILS OF VICTORIAN PILCHARD SAMPLES; ALL PROCURED FROM MELBOURNE FISH MARKET EXCEPT WHERE OTHERWISE STATED

Date	Locality	How Procured	No. Measured
1.viii.37	Lakes Entrance	Beach seine	6
22. ix.37	Port Phillip Bay	Beach seine	13
26. ix.37	Port Phillip Bay	Beach seine	14
26. x.37	Port Phillip Bay		38
4. xi.37	Port Phillip Bay		38
30. xi.37	Port Phillip Bay		62
18. i.38	Port Phillip Bay		70
—. vii.41	Lakes Entrance	Beach seine	1
14. ix.41	Lakes Entrance	Beach seine	1
1. iv.42	Port Phillip Bay		12
18. x.42	Port Phillip Bay		3
19. xi.42	Port Phillip Bay		250
23. xi.42	Port Phillip Bay		1
21. ix.43	Corner Inlet (near Wilson's Promontory)		128
30. x.43	Port Phillip Bay		164
12. xi.43	Port Phillip Bay		158
18. xii.43	Port Phillip Bay		128
22. i.44	Port Phillip Bay		171
21. ii.44	Port Phillip Bay		122
28. iii.44	Port Phillip Bay		129
25. iv.44	Port Phillip Bay		56
25. v.44	Port Phillip Bay		136
7. ix.44	Lakes Entrance		542
12. ix.44	Lakes Entrance		905
8. xii.44	Lakes Entrance		134
20. i.45	Lakes Entrance		68
16. ii.45	Port Phillip Bay		9
15. iii.45	Port Phillip Bay		1
28. v.45	Port Phillip Bay		1
11. vii.45	Westernport		9
22. vii.45	Westernport		124
9.viii.45	Westernport		604
4. ix.45	Westernport		315
24. x.45	Lakes Entrance		119
7. i.46	Port Phillip Bay		179
14. i.46	Port Phillip Bay		210
6. ii.46	Port Phillip Bay		298
9. v.46	Port Phillip Bay	Beach seine	6
2. xi.47	Port Phillip Bay	*Ex* barracouta	1
16. xi.47	Port Phillip Bay	Beach seine	9
27. i.48	Port Phillip Bay		110
4. iii.48	Port Phillip Bay		46
—. ix.48	Port Phillip Bay	Mesh net	9
—. ix.48	Metung, Gippsland Lakes		40
8. xii.48	Port Phillip Bay		426

APPENDIX I (CONTINUED)

Date	Locality	How Procured	No. Measured
10. i.49	Port Phillip Bay		198
26. i.49	Port Phillip Bay		156
2. ii.49	Port Phillip Bay		134
1. vi.49	Port Phillip Bay	Purse-lampara	15
		Total	6,369

APPENDIX II

DETAILS OF TASMANIAN PILCHARD SAMPLES

Date	Locality	How Procured	No. Measured
25.vi.40	Cape Pillar	*Ex* barracouta	1
25. i.41	Fortescue Bay (near C. Pillar)	Mesh net	1
26. ii.41	Fortescue Bay (near C. Pillar)	Beach seine	1
1.iv.41	Oyster Bay	*Ex* barracouta	10
19.iv.41	Fortescue Bay	Beach seine	356
19. v.41	Fortescue Bay	Beach seine	11
		Total	380

APPENDIX III

DETAILS OF SOUTH AUSTRALIAN PILCHARD SAMPLES

Date	Locality	How Procured	No. Measured
16. ii.39	St. Vincent's Gulf	*Ex* southern bluefin tuna	9
3. iii.39	Cape Borda	*Ex* southern bluefin tuna	2
4.xii.39	St. Vincent's Gulf	*Ex* southern bluefin tuna	1
11.xii.39	Backstairs Passage	*Ex* southern bluefin tuna	8
13.xii.39	Antechamber Bay (Kangaroo I.)	*Ex* southern bluefin tuna	4
28. iii.40	Coffin Bay	Lampara	241
1. iv.47	Port River (Adelaide)	Beach seine	1
28. iv.47	Coffin Bay	Lampara	412
11. v.49	Wedge I. (Spencer Gulf entrance)	*Ex* barracouta	16
15. v.49	English I. (Spencer Gulf entrance)	Lampara	14
16. v.49	Taylor I. (near Pt. Lincoln)	Dip net	5
23. v.49	Cape Catastrophe to Coffin Bay	*Ex* southern bluefin tuna	13
24. v.49	Coffin Bay	Lampara	969
		Total	1,695

APPENDIX IV

DETAILS OF WESTERN AUSTRALIAN PILCHARD SAMPLES; SEE SECTION V(*a*) REGARDING AREA NUMBERS

Date	Locality	How Procured	No. Measured
14. i.41	Bunbury	From W.A. Fisheries Dept.	3
24.viii.41	Torbay, near Albany	*Ex* samson fish	2
14. ii.42	Minninup (Area 4)	From W.A. Fisheries Dept.	2
22.viii.42	Torbay	*Ex* southern bluefin tuna	9
21. iv.43	Cheyne Beach (Area 3)	From W.A. Fisheries Dept.	6
5. iv.44	Bunbury	Beach seine	6
21. vi.44	Bunbury	Beach seine	2
17. vii.45	Fremantle	Gunfire concussion	8
26. vii.45	Fremantle	Gunfire concussion	1
6. ix.45	Red Bluff	*Ex* northern bluefin tuna	1
6. ix.45	Two People Bay (Area 3)	*Ex* sea herring	2
—. ii.46	Hopetoun (Area 2)	*Ex* salmon	12
—. v.46	Fremantle	From D. L. Serventy	1
1. vi.46	Bunbury	Beach seine	113
25. i.47	Cape Naturaliste	*Ex* southern bluefin tuna	1
—. iii.47	Bunbury	From W.A. Fisheries Dept.	2
11. v.47	Bellinger I. (Area 2)	*Ex* barracouta	1
12. v.47	Recherche Archipelago (Area 2)	*Ex* barracouta	3
14. v.47	Lucky Bay (Area 2)	Mesh net	622
20. v.47	Bremer Bay (Area 3)	Mesh net	32
20. v.47	Cheyne Bay (Area 3)	*Ex* barracouta	1
21. v.47	Cheyne Bay (Area 3)	Mesh net	3
—. vi.47	Hopetoun	*Ex* salmon	2
11. vii.47	Sandy Hook I. (Area 2)	Mesh net	20
17. vii.47	Point Culver	Mesh net	10
23. xi.47	Geographe Bay	Mesh net	1
24. xi.47	Geographe Bay	*Ex* samson fish	2
25. xi.47	Geographe Bay	Mesh net	7
2. xii.47	Cape Leeuwin	Mesh net	1
12. xii.47	Geographe Bay	*Ex* oriental bonito	1
23. iv.48	Geographe Bay	*Ex* southern bluefin tuna	1
24. iv.48	Geographe Bay	Mesh net	3
25. iv.48	Geographe Bay	Mesh net	15
27. iv.48	Bunbury	Beach seine	8
27. iv.48	Off Busselton (Area 4)	*Ex* oriental bonito	1
13. v.48	Cheyne Bay to Doubtful I. Bay	*Ex* southern bluefin tuna	4
19. v.48	King George Sound	Lampara	111
20. v.48	King George Sound (2 samples)	Lampara	509
23. v.48	King George Sound	Lampara	118
24. v.48	King George Sound	Lampara	132
25. v.48	King George Sound	Lampara	17
27. v.48	King George Sound (2 samples)	Lampara	451
29. v.48	King George Sound	Lampara	402

APPENDIX IV (CONTINUED)

Date	Locality	How Procured	No. Measured
29. v.48	King George Sound	Lampara	1,030
3. vi.48	King George Sound (2 samples)	Lampara	369
9. vi.48	Doubtful I. Bay	*Ex* oriental bonito	3
5. vii.48	Cape Vancouver (Area 3)	*Ex* southern bluefin tuna	2
31. iii.49	Geographe Bay	Perth market	55
15. iv.49	Cape Naturaliste	*Ex* southern bluefin tuna	1
		Total	4,109

EXPLANATION OF PLATES 1-5

Scales of Port Phillip Bay pilchards:

Areas 1-7 refer to parts of the fish, see Section II(*d*) (iv) of text.
A indicates a secondary or accessory ring.
Y indicates a yearly ring, the numeral denoting age in years.
S indicates a spawning ring, the numeral denoting age in years.

PLATE 1

Fig. 1.—From area 4 of fish 146 mm., spent male, taken in February: S3 distinct, partly obliterating Y3, and S4 at edge, partly obliterating Y4.

Fig. 2.—From area 4 of fish 135 mm., recovering male, taken in October: S4 represented by newly torn edge, partly obliterating Y4 and almost obliterating S3. Y2 may be a spawning ring.

PLATE 2

Fig. 1.—From area 4 of fish 138 mm., stage 2 female, taken in October: S3 lacking characteristic spawning-ring appearance, Y4 but not S4 present.

Fig. 2.—From area 1 of fish 131 mm., recovering male, taken in October: compare with subsequent figures, especially S3.

PLATE 3

Fig. 1.—From area 2 of same fish as last, note S3.

Fig. 2.—From area 3 of same fish: note S3, also torn edge indicating S4, not visible in previous figures.

PLATE 4

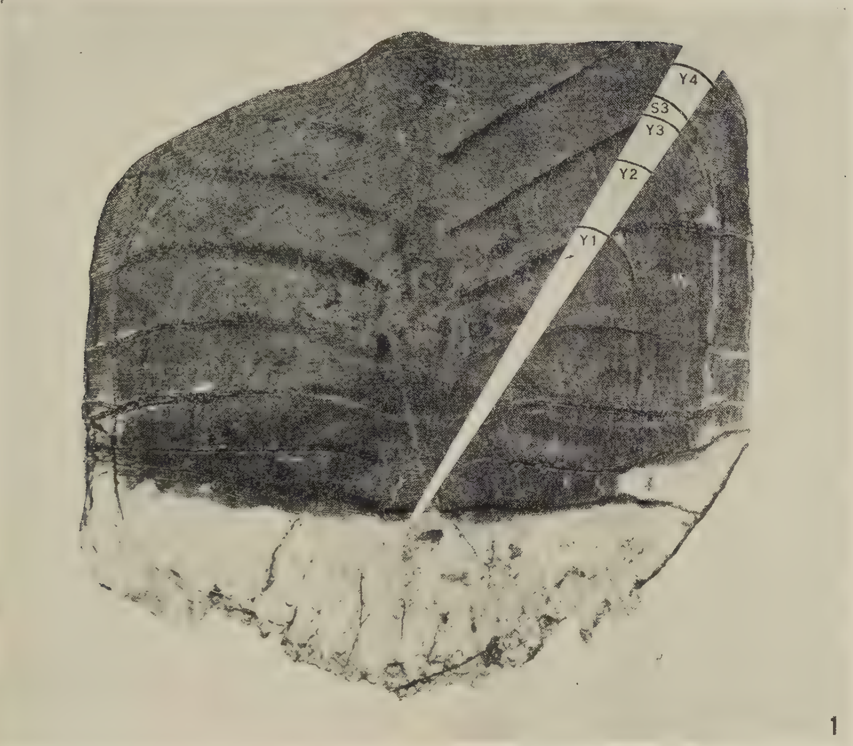
Fig. 1.—From area 4 of same fish: S3 more like characteristic spawning ring than in previous figures.

Fig. 2.—From area 5 of same fish: S3 with characteristic spawning-ring appearance, and torn edge clearly indicating S4.

PLATE 5

Fig. 1.—From area 6 of same fish: S3 as in area 4 scale, not as distinct as in area 5 scale, but more so than in others.

Fig. 2.—From area 7 of same fish: S3 as in area 1, 2, and 3 scales, and edge not obviously torn.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Y3
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Y1
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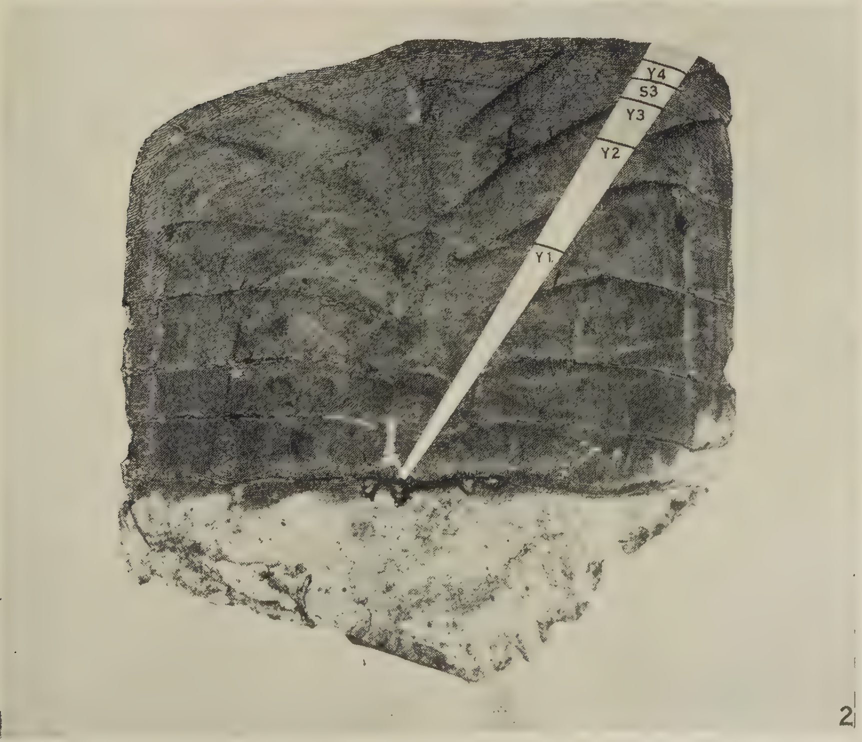
Y4
S3
Y3
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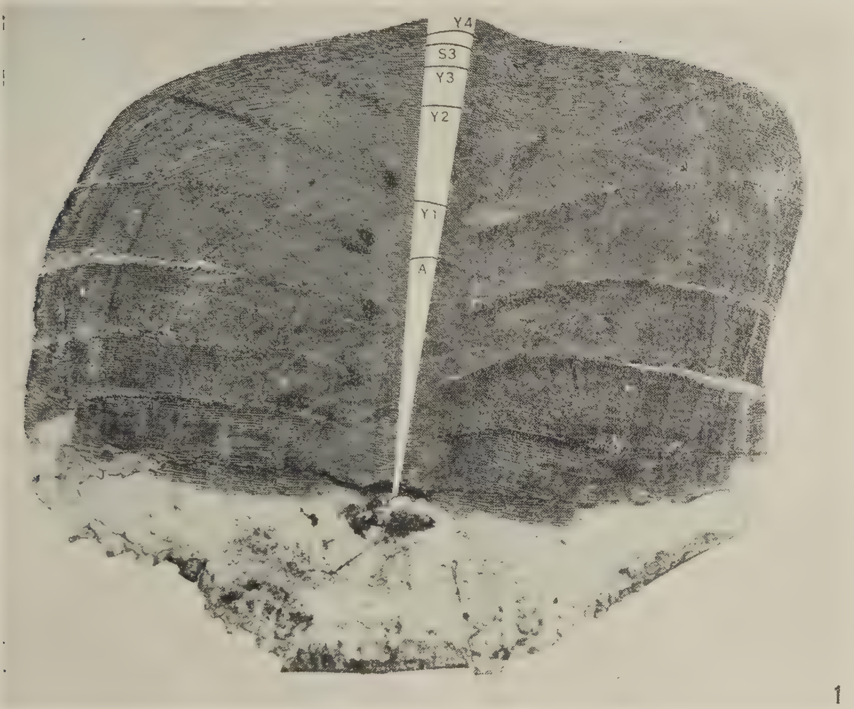
2

BLACKBURN.—STUDIES ON THE AGE, GROWTH, AND LIFE HISTORY OF THE PILCHARD, *SARDINOPS NEOPILCHARDUS* (STEINDACHNER), IN SOUTHERN AND WESTERN AUSTRALIA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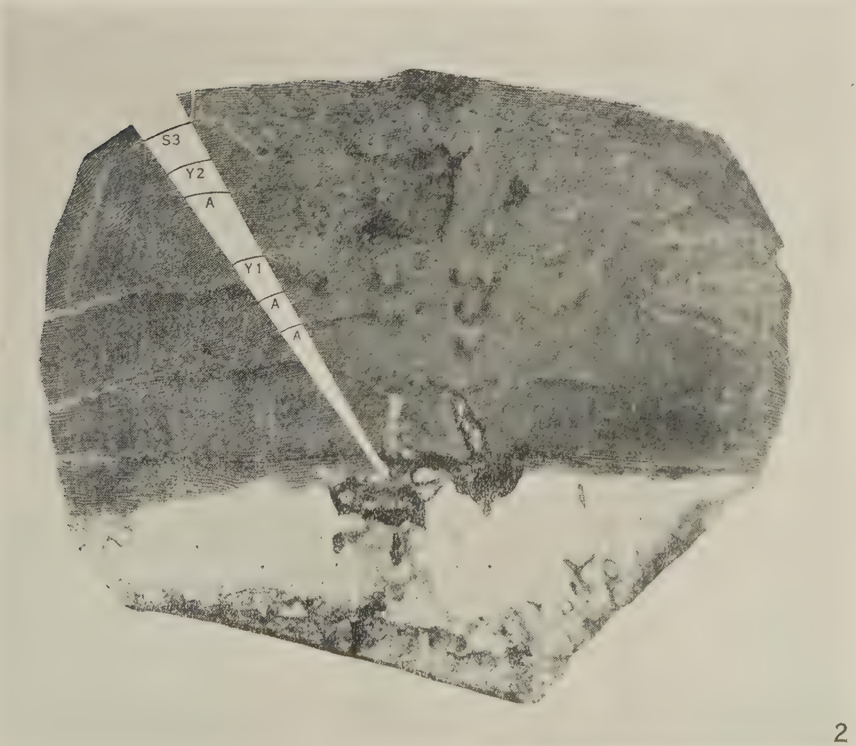
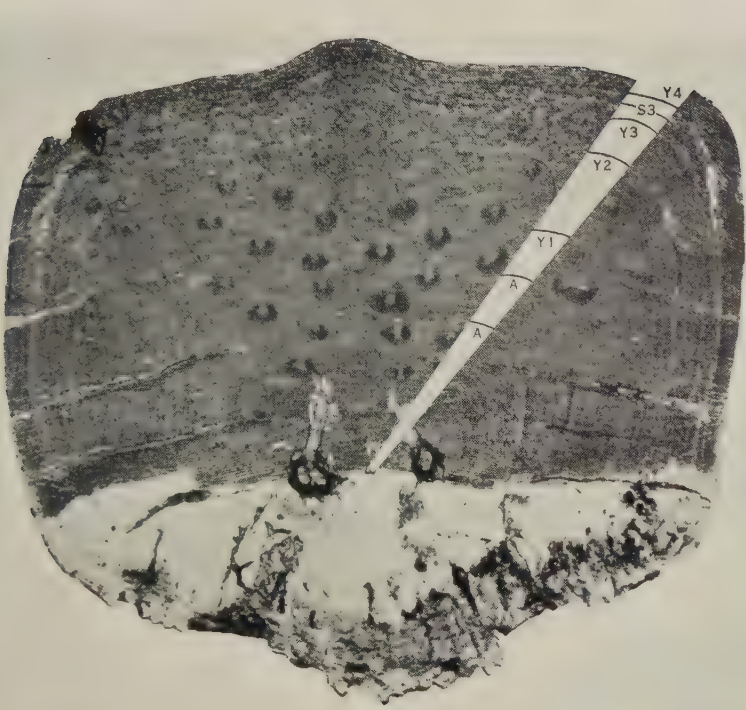


2

BLACKBURN.—STUDIES ON THE AGE, GROWTH, AND LIFE HISTORY OF THE PILCHARD, SARDINOPS NEOPILCHARDUS (STEINDACHNER), IN SOUTHERN AND WESTERN AUSTRALIA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Y3
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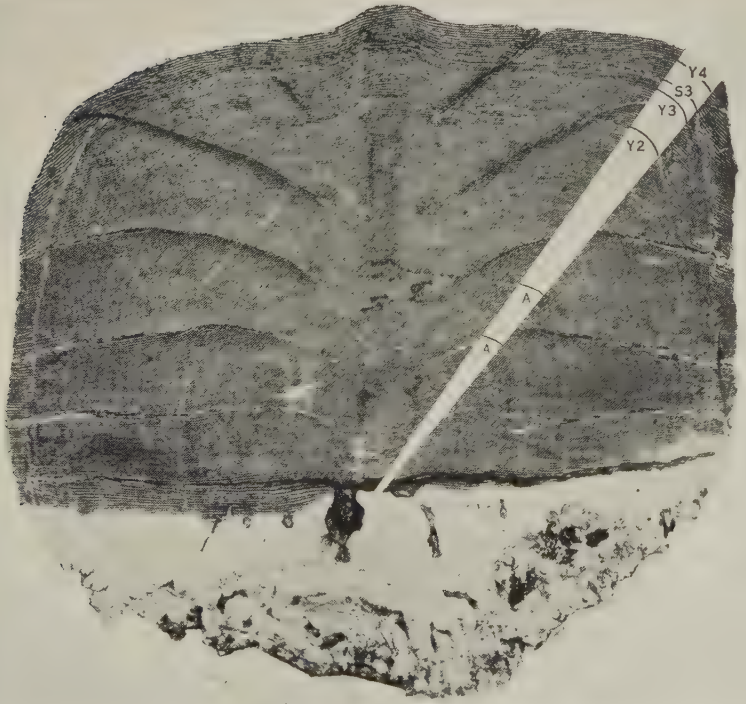
1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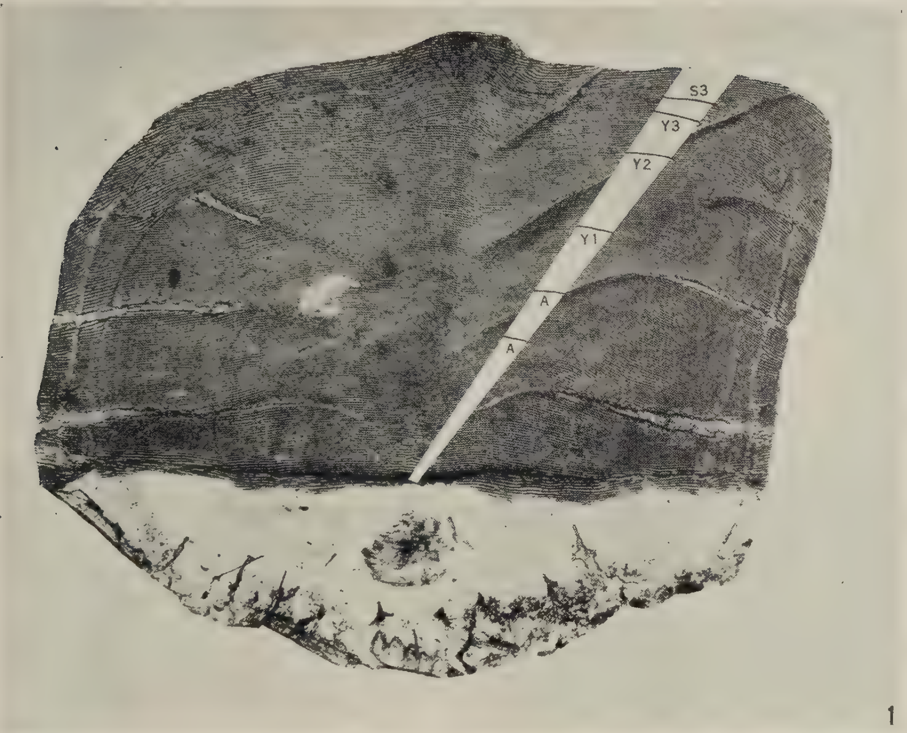
2

Blackburn.—Studies on the Age, Growth, and Life History of the Pilchard, Sardinops neopilchardus (Steindachner), in Southern and Western Australia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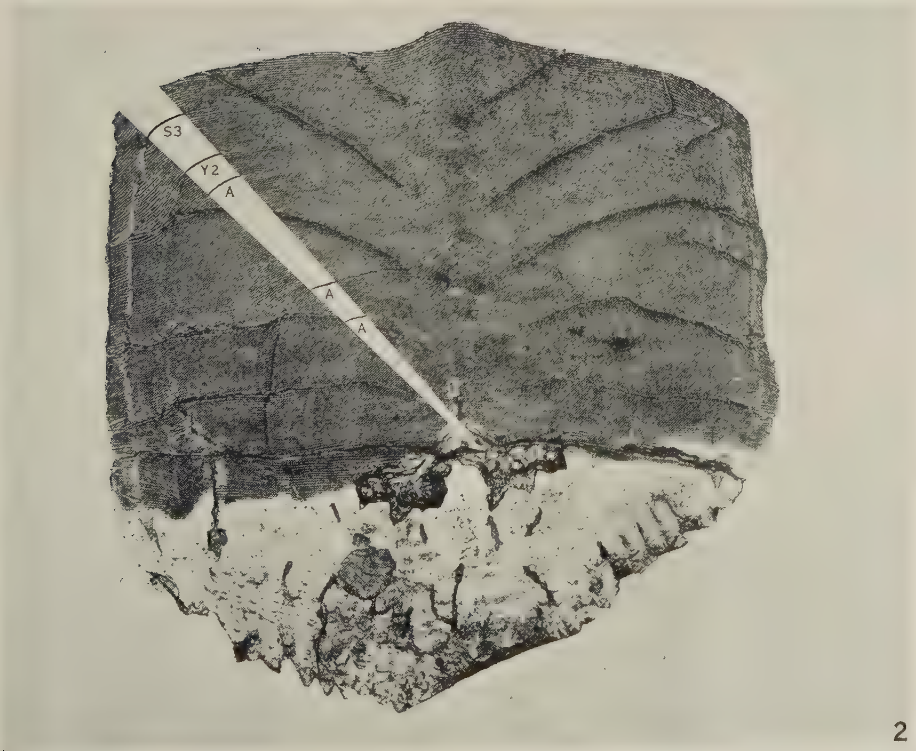
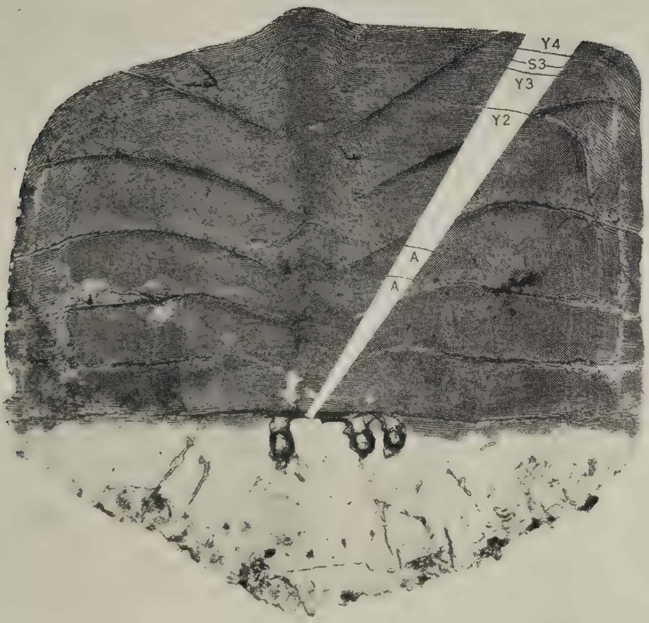


2

BLACKBURN.—STUDIES ON THE AGE, GROWTH, AND LIFE HISTORY OF THE PILCHARD, SARDINOPS NEOPILCHARDUS (STEINDACHNER), IN SOUTHERN AND WESTERN AUSTRALIA

Plate 5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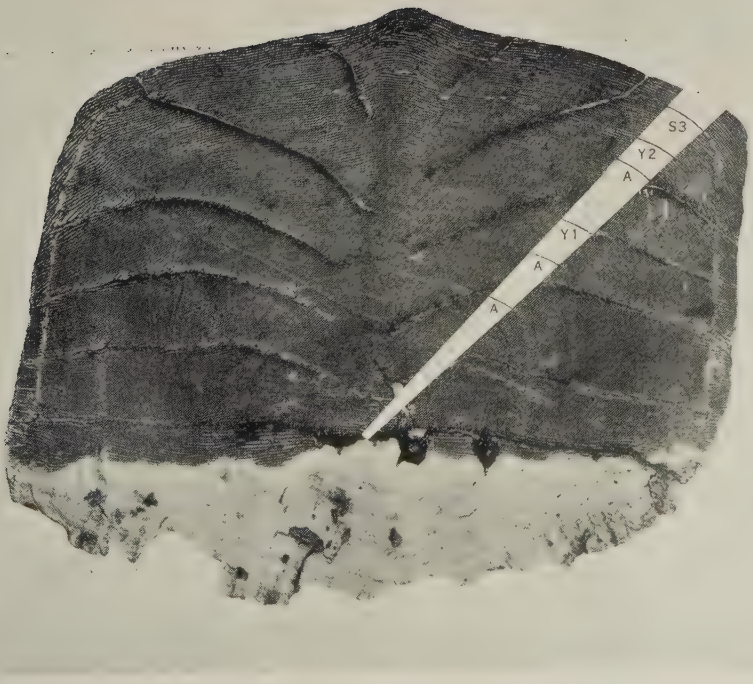

2

Blackburn.—Studies on the Age, Growth, and Life History of the Pilchard, *Sardinops neopilchardus* (Steindachner), in Southern and Western Australia

SHELL MOVEMENTS OF THE FRESHWATER MUSSEL, *HYRIDELLA AUSTRALIS* LAM. (LAMELLIBRANCHIATA)

By I. D. HISCOCK*

(*Manuscript received June* 26, 1950)

Summary

An analysis of about 4,500 hours of shell movement tracings of the freshwater mussel, *Hyridella australis* Lam., is presented. Nine series of experiments have been conducted, representing variations in light and temperature conditions. It has been found that, as well as shell movements, shell position or degree of openness must be considered. The shells may be closed (phase 1), completely open (phase 3), or stationary, intermediate between the two (phase 2), for the validity of which position mathematical proof has been found. The characteristics of each phase have been outlined.

Temperature, within the range 17 to 27°C., shows no well-defined influence on shell movements or the degree of openness. The influence of light, especially in regard to phase 2, is discussed. A diurnal light rhythm is associated with a diurnal feeding rhythm; under continuous illumination the shells tend to remain apart but in phase 2; darkness suppresses shell movements and feeding.

The shell movements during ovulation are discussed.

I. INTRODUCTION

The respiratory ctenidia (gills) of lamellibranch molluscs have become modified to serve as feeding organs, provided with cilia and mucus-secreting cells. The process of feeding depends on three factors: functioning of the ctenidial cilia, movements of the shells, and the activity of the adductor muscles attached to the shells.

An early investigation of the shell movements of lamellibranchs was that of Nelson (1921, 1922, 1923) who studied the feeding habits of oysters in Barnaget Bay, New Brunswick. He concluded that the commencement and termination of feeding were related to time and to tide but not to temperature, providing that the latter was above a critical level of 7°C. Galtsoff (1928), in a study of the function of oyster gills, confirmed Nelson's view that temperature within the range 13 to 22°C. did not affect shell movements; unlike Nelson he found no correlation between periods of opening and time of day and night.

The relationship between temperature and feeding in *Ostrea gigas* was investigated by Hopkins (1931, 1933, 1935). He found that it was not so much the temperature of the water that influenced shell openings as sudden changes in temperature. Loosanoff (1939) found that with the clam *Venus mercenaria* the time during which the shells remained apart depended partly on the temperature of the surrounding water. With the edible mussel, *Mytilus edulis,* he found (1942) no correlation between the duration of openness and temperature within the range —1 to 25°C. Within this range the shells remained open from 78 to 99 per cent. of the total time.

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* Department of Zoology, University of Adelaide, working under a Commonwealth Research Grant.

The only published data on freshwater mussels found by the author are those of Wenrich (1916) and Chipman (1931) who both concluded that temperature and light variations were not correlated with shell movements.

The purpose of the present investigation was to learn something of the feeding habits of *Hyridella australis* Lam., a species widely distributed in Australian rivers, and to determine the effect of various conditions of light and temperature on its shell movements.

II. MATERIALS AND METHODS

Large numbers of *H. australis* were collected from the Murray River, South Australia, principally from Mannum, and were maintained in large outdoor cement tanks. These had a depth of about two feet of water covering a six-inch bed of sandy mud at the bottom. For experimental purposes adult animals, about 80 g. in weight, were taken from the outdoor tanks and placed in indoor aquaria for conditioning to the temperature and other physical conditions under which their shell movements were to be recorded. The indoor aquaria measured 4 × 4½ × 7 in. and the animals were covered with 4 to 5 in. of water.

The apparatus used for recording shell movements differed slightly from that used by Nelson (1921), Galtsoff (1928), Hopkins (1933), and Loosanoff (1939). It consisted of a simple lever system made from quarter-inch strips of 20-gauge aluminium. The animals were fixed to three-inch squares of plate glass with melted pitch by the deepest portion of the left shell, thus placing the hinge and shell margins in a horizontal plane. The vertical lever was attached to the animal by a loop of wire sealed in "Dental Sticky Wax" to the right (upper) shell margin. The fulcrum of the horizontal lever was arranged to give an amplification of the shell movement of about five times. The animals were then replaced in the aquarium jars and the lever system carefully counterbalanced. The water in each jar was replaced daily and received no artificial aeration. Under these conditions the animals remained healthy and showed no loss of weight for the duration of the experiments.

Records of the shell movements were made on smoked paper on clockwork kymographs. These were geared to make one revolution in 24 hours, but the design of the instruments allowed only of 22½ hours recording being made in each day.

The experiments were designed to show the influence of light and temperature on shell movements. Three temperatures were used for the experiments, 16 to 17° C., 22°C., and 27°C. Each specimen was held at the temperature at which it was to be tested for at least one month prior to recording. Three conditions of illumination were used, viz. diurnal light rhythm, constant illumination from one 60-watt lamp fixed four feet above the aquaria, and darkness. Each condition of illumination was tested at each of the three temperatures, comprising nine series of experiments.

For an analysis of the recordings, the area between the record line and the reference line (complete closure) was calculated by tracing the recording on to metric sectional drawing paper. The following values were obtained for each recording:

(1) The total area enclosed, representing 22½ hours.

(2) The average area enclosed per hour.

(3) The area enclosed in successive 2½-hour periods, these being an arbitrary division of each 22½ hours into nine periods, referred to as periods 1 to 9.

(4) The percentage of time during which the shells remained apart.

III. EXPERIMENTAL RESULTS

The total number of daily recordings made was 186, representing about 4,500 hours of tracings. The experiments were conducted in nine series representing variations in light and temperature, each series representing 400-500 hours of tracing. The average results for the nine series are shown in Table 1.

TABLE 1

SHOWING THE AVERAGE SHELL OPENINGS IN THE NINE SERIES
(Expressed as sq. mm. per hr.)

Temperature (°C.)	Diurnal Light Rhythm	Constant Illumination	Darkness
17	218	104	87
22	96	124	86
27	247	79	87

The term "shell movements" in the literature has been applied both to the movements of the shells and to their degree of openness. As will be shown subsequently, it is necessary to distinguish between the two terms. In this paper "shell movements" means only the actual movements of the shells. The distance apart is expressed as "degree of openness."

(a) *The Influence of Temperature*

As Table 1 shows, there was no definite relationship found between the temperature and degree of openness. Also, within the temperature range 17 to 27°C. there was no correlation between temperature and shell movements. *H. australis,* therefore, is similar in this respect to the marine lamellibranchs studied by Nelson (1921), Galtsoff (1928), Hopkins (1933), and Loosanoff (1939).

(*b*) *The Influence of Light*

Under the influence of a normal diurnal light rhythm, within the temperature range 17 to 27°C., *H. australis* opened its shells to a greater extent than when under constant illumination or in darkness.

Unlike the findings of Galtsoff (1928) for *Ostrea* and those of Loosanoff (1939) for *Mytilus edulis,* these results showed that with *H. australis*, there was a distinct relationship between shell opening and time of day. The shell movements showed a marked diurnal rhythm with the opening greatest during periods 3 to 6, i.e. during the night (Fig. 1). Period 1 commenced at 11.30 a.m. and period 9 ended at 10 a.m. the following day.

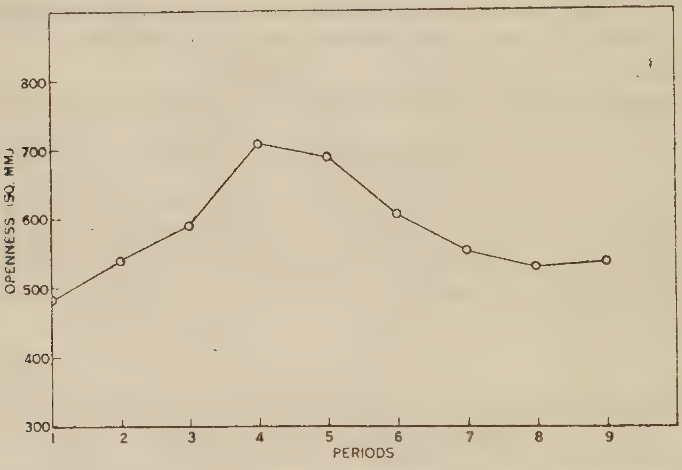

Fig. 1.—Showing the degree of openness at the nine 2½-hour periods under the influence of a diurnal light rhythm, within the temperature range 17° to 27°C.

Under constant illumination or in darkness there was no correlation between shell opening and time of day.

Analysis of the kymograph tracings showed that the shells may occupy any one of three well-defined positions, viz., closed, partly open, or fully open. By plotting the frequency distribution of the number of 2½-hour periods at different degrees of openness (excluding complete closure) an apparently bimodal distribution was obtained in each case, i.e. the nine series of experiments. The distribution was analysed by the method of Harding (1949) using probability paper. In each case the distribution was divisible into two populations with mean values of approximately 200 and 800 sq. mm. per period. Figure 2 shows the frequency distribution and its analysis for the series Constant Illumination, 22°C.

The three shell positions or *phases* can be classified as follows:

Phase 1.—Complete closure of the shells, no shell movements, no feeding. (Subsequent evidence has shown that a young *H. australis* accidentally left in a dry aquarium jar had withstood desiccation at 22°C. for at least three months by keeping its shells completely shut).

Phase 2.—Prolonged partial closure with the shells *stationary,* 1 to 3 mm. apart, the two siphons not protruded beyond the shell margin posteriorly. There was apparently no active feeding, i.e. no detectable pumping of water, using a fine carmine suspension as an indicator.

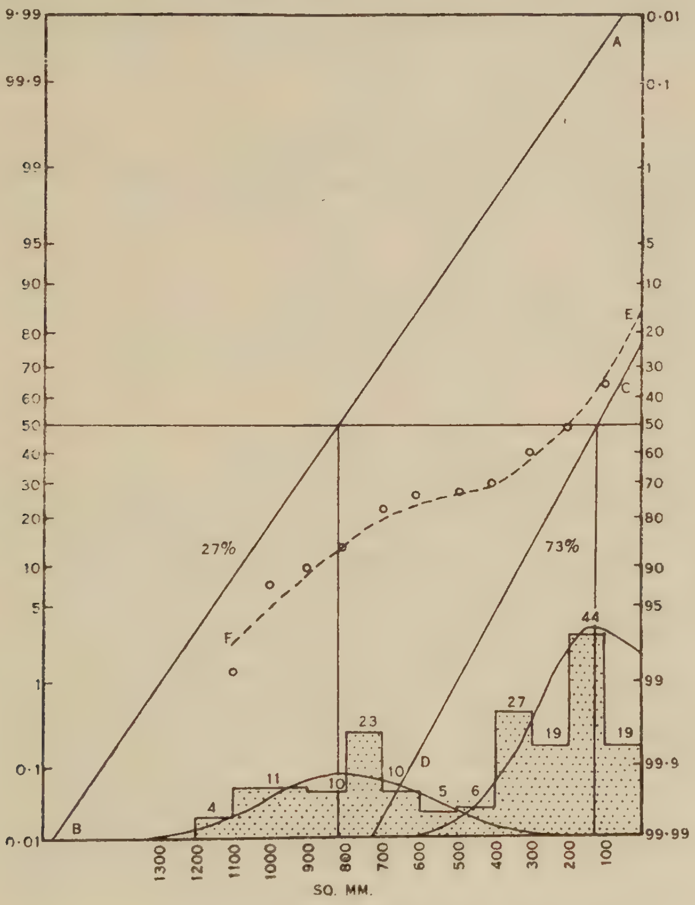

Fig. 2.—Showing the analysis on probability paper of the frequency distribution of the number of periods at different degrees of openness (shown in the histogram) for the series 'Constant Illumination, 22°C.' The lines AB and CD were found by assuming that the distribution was a bimodal one due to two phases in the degree of openness of the shells. The dotted line EF is the resultant of the two straight lines AB and CD.

Phase 3.—Complete opening, active feeding, siphons protruding, shell movements frequent.

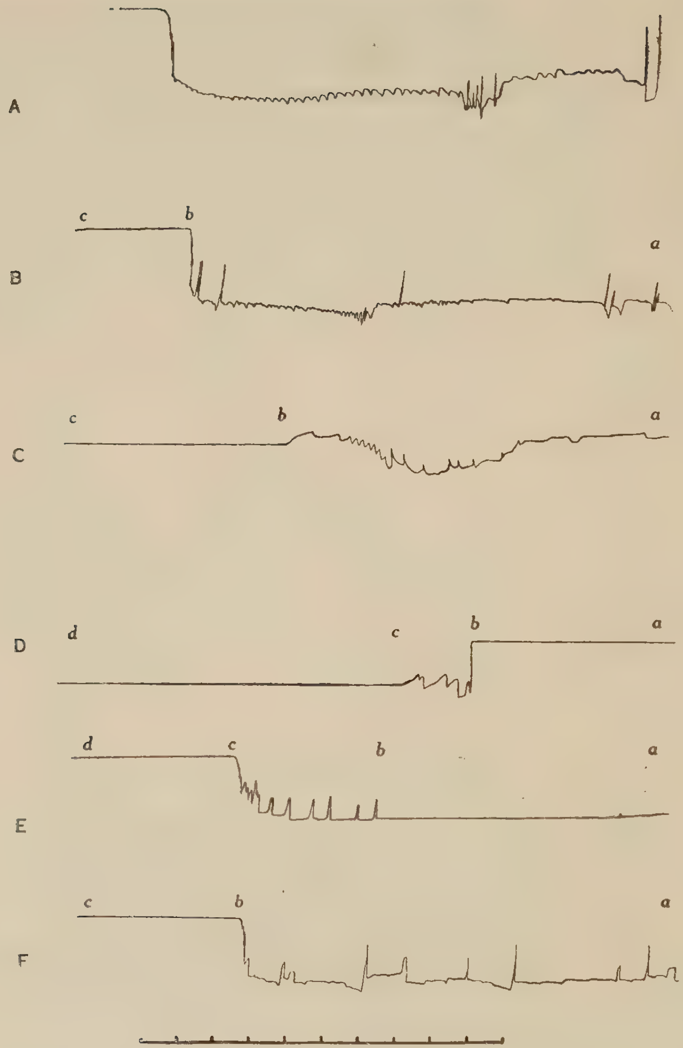

Fig. 3

A. Showing slight, rhythmical shell movements in phase 3.
B. *a-b*, Phase 3, with frequent slight shell movements, followed by *b-c*, phase 1.
C. *a-b*, Phase 3, followed by *b-c*, phase 2.
D. *a-b*, Phase 1, followed by *b-c*, short phase 3, followed by *c-d*, phase 2, which is prolonged.
E. *a-b*, Phase 2, followed by *b-c*, phase 3, then *c-d*, phase 1.
F. *a-b*, Phase 3, with irregular shell movements, followed by *b-c*, phase 1.

Tracing moves from right to left. Time mark 30 minutes.

The shell movement tracings showed that phase 1 was followed always by a period of active feeding, i.e. phase 3. After a varying time in this phase, the animals entered phase 1 again or phase 2. Figure 3 shows the characteristics of these three phases in the tracings.

Temperature, within the range 17 to 27°C., had no influence on the shell positions. Light, on the other hand, showed a marked influence, as illustrated in Table 2.

TABLE 2

PERCENTAGE OF TIME IN EACH PHASE UNDER THE THREE CONDITIONS OF ILLUMINATION

	Phase 1	Phase 2	Phase 3	Total Time Open, Phase 2 and 3
Diurnal light rhythm	36	19	45	64
Constant illumination	36	36	28	64
Darkness	47	27	26	53

Under the influence of a diurnal light rhythm *H. australis* tended to remain fully open (phase 3) or closed (phase 1) rather than partially closed (phase 2). On an average 64 per cent. of the time was spent with the shells apart. This figure gives no account of individual variation; during one experiment one animal remained completely closed for 100 per cent. of the time; in 12 other experiments various animals remained open (phase 2 or 3) for 100 per cent. of the time.

Under constant illumination the shells remained apart as much as under a diurnal light rhythm, but mainly in phase 2. In one experiment one animal remained completely closed for 100 per cent. of the time; in 36 other experiments various animals remained open for 100 per cent. of the time, but in the latter case mostly in phase 2.

In darkness the shells remained apart for 53 per cent. of the time (phases 2 and 3 approximately equal).

(*c*) *Shell Movements during Ovulation*

In *H. australis*, as in most freshwater lamellibranchs, the sexes are separate. The ova in the female, when fertilized, pass to the ctenidial cavities (marsupium) and there develop to typical glochidium larvae. These eventually pass to the suprabranchial cavities and are expelled into the surrounding water in a stream of mucus, the process being assisted by movements of the shells. Only two records of shell movements during ovulation have been made in this laboratory; these were apparently the first recorded for a freshwater mussel. The shell movements were much more frequent than normal and the shells were brought together periodically and very rapidly. The mucus strings expelled at each movement contained from 100 to 200 glochidia. The process has been observed to continue for 36 hours. A tracing of ovulatory shell movements is shown in Figure 4.

IV. Discussion

The movements of the shells of lamellibranch molluscs may serve to relieve fatigue of the adductor muscles (Orton 1935), to rid the ctenidia of mucus accumulations, to expel faeces from the rectum through the exhalent siphon, or "pseudofaeces" from the mantle edges, and to expel larvae from the suprabranchial cavities. It has not been established previously that either temperature or light has a direct influence on shell movements.

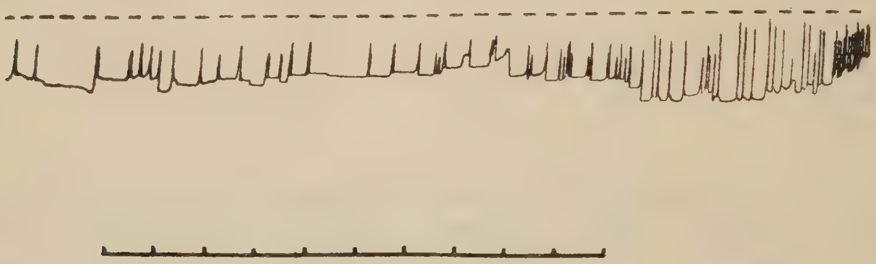

Fig. 4.—Frequent and rapid shell movements recorded at the commencement of ovulation. The base line, representing complete closure, is shown as a dotted line. Tracing moves from right to left. Time mark 30 minutes.

The experiments on *H. australis* have shown that temperature, within the range 17 to 27°C., does not affect shell movements as much as light, which has a marked effect. As illustrated in Table 1, the greatest activity is shown under the influence of a diurnal light rhythm which also induces a diurnal rhythm in shell movements (Fig. 1). The experiments have shown also that as well as shell movements, shell position or the degree of openness must be taken into account. The shells may be closed, partially closed, or fully open. Using the method of Harding (1949), it has been possible to establish mathematical proof of the reality of these three positions or phases. Bayliss (1924) pointed out that certain invertebrate muscular systems, such as the adductor muscles of molluscs, are able to maintain a shortened state for long periods without evidence of fatigue. This state of fixation can occur at any length of the muscle fibres and with any tension. In phase 1 (closure) the adductor muscles are fully contracted, feeding ceases, and in clams, Koehring (1937) has found that heart-beat ceases. In phase 2 the adductor muscles, which in *H. australis* are of smooth fibres only, enter a state of prolonged tonic contraction which, coupled with reduction or cessation of feeding, enables the animal to continue respiration with little expenditure of energy and practically no fatigue.

Though temperature does not influence the degree of openness, it ay influence the rate of feeding. The rate of flow of water produced the activity of the ctenidial cilia has been shown by Gray (1924) and altsoff (1926, 1928) to be a function of temperature. Hence, though e shells are not opened to a greater extent at higher temperatures, it es not necessarily mean that the total quantity of water passed through e ctenidia per day is not higher.

It seems probable that under a diurnal light rhythm feeding in *H. stralis* is at a maximum. When this normal rhythm is upset by con- uous illumination feeding occupies less time. Though the shells remain art for as long a time as before, they tend to remain in phase 2. olonged darkness depresses feeding and when the shells are apart, half the time is spent in phase 2.

These facts are of interest because there are no records of bivalve olluscs, either marine or freshwater, having been subjected to conditions continuous illumination or darkness. That the phases are not the result experimental conditions is shown by their occurrence under a normal urnal light rhythm.

When the glochidia larvae of *H. australis* are expelled from the female, e shell movements are very frequent and almost rhythmical. The shells en slowly and come together rapidly, expelling the glochidia in mucus rings through the exhalent siphon. It seems probable that the stimulus r this increased activity is a chemical one.

V. ACKNOWLEDGMENTS

It is a pleasure to record my gratitude to Professor T. Harvey hnston and Mr. I. M. Thomas, Professor and Senior Lecturer, spectively, in Zoology at the University of Adelaide, for their helpful lvice during the course of this work. I am especially indebted to Miss E. Neylon, Technician, of this Department, who undertook the mathematical alysis of the results.

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